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SURVIVABILITY DESIGN GUIDE FOR U. S. ARMY AIRCRAFT

VOLUME I

SMALL-ARMS BALLISTIC PROTECTION

By

Walter D. Dotseth

November 1971

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-70-C-0044
LOS ANGELES DIVISION
NORTH AMERICAN ROCKWELL CORPORATION
LOS ANGELES, CALIFORNIA

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EUSTIS DIRECTORATE
FORT EUSTIS, VIRGINIA 23604

(U) This first edition of Small-Arms Ballistic Protection Survivability Design Guide for U. S. Army Aircraft was prepared by North American Rockwell, Los Angeles Division, under the terms of Contract DAAJ02-70-C-0044.

(U) Under the contract, Army aircraft survivability design data generated over the past ten years were compiled and analyzed in the area of aircraft vulnerability reduction and aircrew protection against small-arms fire. From this source of information, pertinent design data related to aircraft vulnerability reduction and aircrew protection were selected and developed into this design guide for use by aircraft engineers, designers, and other personnel responsible for Army aircraft survivability.

(U) The contents of this guide have been coordinated with the Air Force Flight Dynamics Laboratory, Army Ballistic Research Laboratories, and the Army Materials and Mechanics Research Center. It is expected that revisions will be made and published from time to time to correct and update the guide and to add pertinent information as it becomes available.

(U) Comments or suggestions pertaining to the data contained in this guide will be welcomed by this Directorate.

(U) The technical monitor for this contract was Mr. Stephen Pociluyko, Safety and Survivability Division.

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VOLUME I

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Los Angeles Division of North American Rockwell

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U.S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

ABSTRACT

An extensive literature and information search was conducted to identify military aircraft small arms protection enhancement techniques developed during the past 10 years. This data was analyzed and used to develop a comprehensive survivability design guide for incorporation of ballistic protection features in U.S. Army aircraft. The design guide is structured for use by aircraft configuration and subsystem design organizations. It provides guidance for overall survivability design considerations and detailed information on specific enhancement techniques. The greatest amount of the design guide information is unclassified and is contained in this document to facilitate its use by individual designers. Special classified information has been placed in Volume II (USAAMRDL Technical Report 71-41B) for use by design specialty areas.

FOREWORD

This document was prepared for the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, by the Los Angeles Division of North American Rockwell Corporation under Contract DAAJ02-70-C-0044 (Task 1F162203A15003). The data contained in this publication was obtained through an extensive search of related published documents and other data developed during the past 10 years. Appreciation is extended to the following military activities for providing information and guidance required for specific portions of the research effort:

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- U.S. Army Human Engineering Laboratory
- U.S. Army Combat Developments Command
- U.S. Army Materials and Mechanics Research Center
- U.S. Army Natick Laboratories
- U.S. Army Board for Aviation Accident Research

Acknowledgement is also extended to those aircraft manufacturers who provided data and information on survivability/vulnerability features of their aircraft for use in this publication.

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INTRODUCTION

U.S. Army aircraft have, within the past decade, been required to perform combat roles where they have been exposed to extremely high concentrations of enemy ground fire. The intensity and magnitude of those weapon effects have exceeded the levels envisioned for these aircraft when originally designed and produced. As a result, loss rates were experienced that have promoted extensive research and testing to develop effective means of reducing aircraft vulnerability. The diversity of these efforts, which have been directed toward many different techniques and concepts to provide ballistic protection to combat aircraft, has dictated the need for a comprehensive document that addresses the specific methods for enhancing aircraft survivability in their operating environments that can be used by designers and program managers responsible for development or modification efforts. This design guide has been developed for that purpose. It contains information on:

- Survivability design factors
- Hostile weapon systems
- Survivability enhancement techniques
- Related trade-off study factors

In this initial edition, protective techniques against hostile small-arms weapon are presented. This includes those visually aimed guns available to forces hostile to the United States, up to and including 14.5 mm projectile sizes. They are the predominant threat to U.S. Army aircraft and, as such, have been given first priority for the design guide. They include ball and armor-piercing type ammunition with and without incendiary and/or tracer features.

Rotary-wing aircraft (helicopter) design features have been emphasized since they represent the greatest portion of the U.S. Army aircraft inventory and have been the most exposed to combat environments. The importance of evaluating the trade-off factors associated with each candidate protection technique has been stressed to insure that effective and realistic priorities are established for specific aircraft design configurations.

This guide has been structured to permit the incorporation of information and design guidance for protection against more potent and sophisticated weapon systems that Army aircraft may be called upon to face in the future. These include the larger size antiaircraft artillery and surface-to-air missile systems that employ high explosive-fragmenting warheads with varied fuzing capabilities and radar or infrared (IR) acquisition, aiming, and/or terminal guidance features.

CHAPTER 1

AIRCRAFT SURVIVABILITY DESIGN FACTORS

1.1 INTRODUCTION

1.1.1 PURPOSE

This design guide has been developed to provide aircraft designers and program managers with the most current information and guidance for passive ballistic protection of U. S. Army aircraft against hostile small-arms weapons. Such protection must be incorporated as part of the initial design of new aircraft to obtain the most effective combination of survivability enhancement features. Experience has shown that only limited protection can be retrofitted into an existing aircraft, and at significant weight, performance, and cost penalties. This has occurred where specific military aircraft have, of necessity, been employed in combat situations for which they were not originally designed and were exposed to intensive small-arms fire. The design did not include specific ballistic protection and, as a consequence, suffered high loss rates. New Army aircraft specifications do contain such requirements. The information in this design guide is structured for use in both initial design and retrofit efforts. Rotary-wing aircraft have been emphasized since they constitute the greatest portion of the U.S. Army aircraft inventory and are exposed to the highest concentration of enemy small-arms fire in the performance of their combat missions.

Special care has been taken to present the maximum amount of design information in an unclassified document to facilitate its availability and use by designers. Volume II is provided that contains essential classified information up to the level of Confidential. References are provided for sources of pertinent or related information that may be needed by the designer.

1.1.2 USE OF DESIGN GUIDE

This guide has been arranged to provide both general configuration and specific design information. It is presented in five chapters, each containing a category of survivability/vulnerability information. The basic elements contained in each chapter are:

- Chapter 1. Aircraft Survivability Design Factors

  Specific definitions
  Vulnerability assessments

- Chapter 2. Ballistic Threat Characteristics

  Hostile small-arms systems
  Projectile types
  Ballistic data

- Chapter 3. General Protection Techniques

  Minimized detection
  Redundancy/separation
  Isolation
  Damage tolerance/resistance
  Leakage suppression/control
  Fire/explosion suppression
  Fail-safe response
  Material selection
  Masking/Armor

- Chapter 4. Specific Design Protection Techniques

  General configurations
  Structures
  Personnel stations
  Fuel systems
  Propulsion systems
  Transmissions
  Environmental control systems
  Flight control systems
  Fluid power systems
  Armament systems
  Electrical power/avionics systems
  Landing systems

- Chapter 5. Trade-off Study Factors

  Critical subsystems/components identification
  Vulnerability and survivability assessment
  System cost effectiveness analysis
  Effectiveness factors determination
  Design management direction

Each chapter has been sequenced to present information in the order of use to acquaint the reader with the subject of survivability and vulnerability. General information on aircraft survival is given first, then areas of specific interest, and then the effect of survivability features for the overall system.

1.2 DEFINITION OF SURVIVABILITY/VULNERABILITY TERMS

Precise definition of survivability/vulnerability terms in relation to U.S. Army aircraft is essential to a fully coordinated design effort. The following definitions have been established for use in this design guide and are to be used as the criteria for conventional weapon survivability enhancement efforts. For questions or additional clarification of these terms, or the establishment of new term definitions, consult the U.S. Army Ballistic Research Laboratories, Aberdeen Proving Grounds, Maryland.

1.2.1 SURVIVABILITY

Aircraft survivability is defined as:

> "That measure of an aircraft's capability to continue to function after being hit by hostile weapon systems. This includes those design and performance features that enable an aircraft, by avoidance or suppression techniques, to degrade a hostile force's ability to use its weapons effectively."

The term "survivability" may be applied to a specific encounter with a hostile weapon system as well as to an overall combat mission. It is usually expressed as a probability of survival (P_S), on a scale of zero to one.

Frequently, the terms "survivability" and "vulnerability" have been used interchangeably, but they are not synonymous. The probability of an aircraft's survivability (P_S) in combat is dependent primarily on three factors; specifically, probability of detection (P_D), probability of a hit (P_H), and the probability of a kill given a hit ($P_{K/H}$).

Each of these factors is important, and each should be considered, regardless of the enemy weapons employed. An increase in survivability is gained by a reduction in the probability of being detected, being hit, or being killed. The probability of being detected is influenced by terrain, weather, speed, altitude, radar reflectivity, noise, etc. The probability of being hit when detected is influenced by altitude, speed, size of aircraft, etc. Many of these influencing factors (for example, altitude, speed, and size of aircraft) are dictated by the mission of the aircraft and cannot be altered significantly. However, a factor which is just as important as or perhaps even more important than any of these in terms of combat survival is the ability of the aircraft to withstand the effects of hits from enemy gunfire.

1.2.2 VULNERABILITY

Aircraft vulnerability is defined as:

> "That quantitative measure of an aircraft's response to a given hostile weapon effect, and the encounter condition, that results in attrition, crew injury, or inability to perform those functions essential to achieve combat mission objectives."

Vulnerability is measured in terms of "vulnerable areas" and is usually expressed in units of square feet or meters for a given aspect direction, specific projectile type and size, striking velocity, and kill category of interest. Vulnerable areas can be expected to vary with changes in each of the foregoing parameters. Therefore, no single value can be used precisely to denote the vulnerability of the aircraft to all hostile weapons. However, useful averages can be and are derived.

The vulnerable area (A_V) of a component, or aircraft, is defined as the product of its presented area (Ap) and the probability of a kill given a hit ($P_{K/H}$). The total vulnerable area (A_{VT}) of an aircraft is the sum of its components vulnerable area; i.e.,

$$A_{VT} = \sum_{i}^{n} A_{Vi} + A_{Vi+1} \cdots\cdots + A_{VN}$$

1.2.3 KILL CATEGORIES

For many years, the vulnerability of aircraft to conventional weapons has been assessed for specific conditions of response due to weapon damage. These "kill categories" were derived for fixed-wing aircraft and are still applicable.. The utilization of helicopters in military combat operations has dictated the need for kill level categories unique to this type aircraft. The following are definitions generally used for each type of aircraft. They may be modified and/or tailored for specific aircraft by the Procuring Agency.

1.2.3.1 Rotary-Wing Aircraft

1.2.3.1.1 Attrition: Damage that will cause the aircraft to crash and become a complete loss.

1.2.3.1.2 Forced Landing: Damage that will cause the pilot to land (powered or unpowered) because he receives some indication of damage (a red light, a low fuel level, difficulty in operating the controls, a loss of power, etc). The extent of damage may be such that very little repair would be required to fly the aircraft back to the base; however, had the pilot continued to fly, the aircraft would have been destroyed. The forced landing kill category includes a forced landing anytime after damage occurs.

1.2.3.1.3 Mission Kill: Damage that will cause a particular mission to be aborted. It is possible to have this level of damage without incurring attrition or forced landing levels of kill.

1.2.3.2 Fixed-Wing Aircraft

1.2.3.2.1 "KK" Kill: Damage that will cause the aircraft to disintegrate immediately in the air (such damage that would render a kamikaze attack ineffective).

1.2.3.2.2 "K" Kill: Damage that will cause the aircraft to fall out of manned control immediately.

1.2.3.2.3 "A" Kill: Damage that will cause the aircraft to fall out of manned control within 5 minutes. ("A" kill includes "K" kill.)

1.2.3.2.4 "B" Kill: Damage that will cause the aircraft to be unable to return to its base. The distance to the base will be fixed for the particular type of mission being assumed. ("B" damage includes the "K" and "A" kills.)

1.2.3.2.5 "C" Kill: Damage that will cause a particular mission to be aborted. It is possible to have "C" damage even though no "K," "A," or "B" damage exists.

1.2.3.2.6 "E" Kill: Damage that will cause the aircraft to be structurally damaged while landing so that repairs will be necessary prior to another flight. Damage to a wheel rim resulting from landing on a flat tire, and changing a flat tire are not considered as "E" damage.

1.3 VULNERABILITY ASSESSMENTS

As previously indicated, there is no single quantitative value that will describe the vulnerability of an aircraft to small-arms weapons precisely

and completely, but rather a compilation of many values, each of which are dependent upon variable parameters, as follows:

- Size and type of projectile
- Striking velocity
- Kill categories and mission objective definitions
- Threat aspect direction
- Vulnerable components characteristics

Vulnerability of an aircraft is usually determined for the six cardinal directions normal to its design reference system; i.e., front, back, left side, right side, top, and bottom.

1.3.1 VULNERABILITY ASSESSMENT PROCEDURE

The following is a nine-step process, used by the U.S. Army Ballistic Research Laboratories, to assess an aircraft's vulnerability to conventional weapons. It is presented to aquaint the reader with an assessment procedure and insight to the sensitivity of specific design areas to ballistic threats.

a. Obtain detailed technical description of the aircraft down to the individual component level.

b. Define levels of kill for the specific aircraft and missions.

c. Determine kill criteria for each subsystem and related components. This is accomplished by analysis to determine which kill category(ies) each component can contribute, for any damage mechanism from ballistic threat.

d. Determine damage criteria for each component. This is accomplished by determining the amount or extent of damage which must be inflicted on a component to meet the kill criteria for the specified kill levels.

e. Determine threat damage potential. The amount of damage that each specified threat can inflict upon components must be established. This is usually accomplished by controlled firing tests upon static and dynamic component setups.

f. Determine the probability of kill given a hit ($P_{K/H}$). The data from step e. is used to determine the $P_{K/H}$ for each component and the specific ballistic threats.

g. Develop a model of aircraft critical components. The size and relative locations of each critical component is established by a physical scale model or by detailed installation drawings (i.e., aircraft inboard profile drawing).

h. Determine critical components presented areas. By use of the data developed in step g., the presented areas of critical components may be determined for each aspect angle of interest. This may be accomplished by direct measurement or computerized methods.

i. Determine aircraft vulnerable areas. This step is accomplished by multiplying the presented area of each critical component by the appropriate $P_{K/H}$. The summation of these vulnerable areas is the total vulnerable area of the aircraft.

1.3.2 SUBSYSTEM REDUNDANCIES

When assessing the vulnerability of a subsystem, redundancies of operation must be considered. This requires a close examination of the system and its mechanization. One method of such analysis is the use of a functional flow diagram. Figure 1 shows an example for a helicopter flight control system.

Redundancies are indicated by the use of "OR" gates where any one input will allow system operation. "AND" gates in the diagrams indicate where all inputs are needed for system operation.

1.3.3 THREAT/VULNERABLE AREA RELATIONSHIPS

The vulnerability of an aircraft is sensitive to the size, type, striking velocities, and aspect angles or projectiles. These measurements are useful in determining the most vulnerable subsystems and components, critical aspect angles, and their relationship to the threat size, type and angles of fire.

Figure 2 shows a means of comparing the vulnerability of the six major aspect angles (top, bottom, right side, left side, front, and rear) of a typical aircraft, for one projectile type, size, striking velocity, and angle of obliquity. It is shown for the "attrition" kill level. The

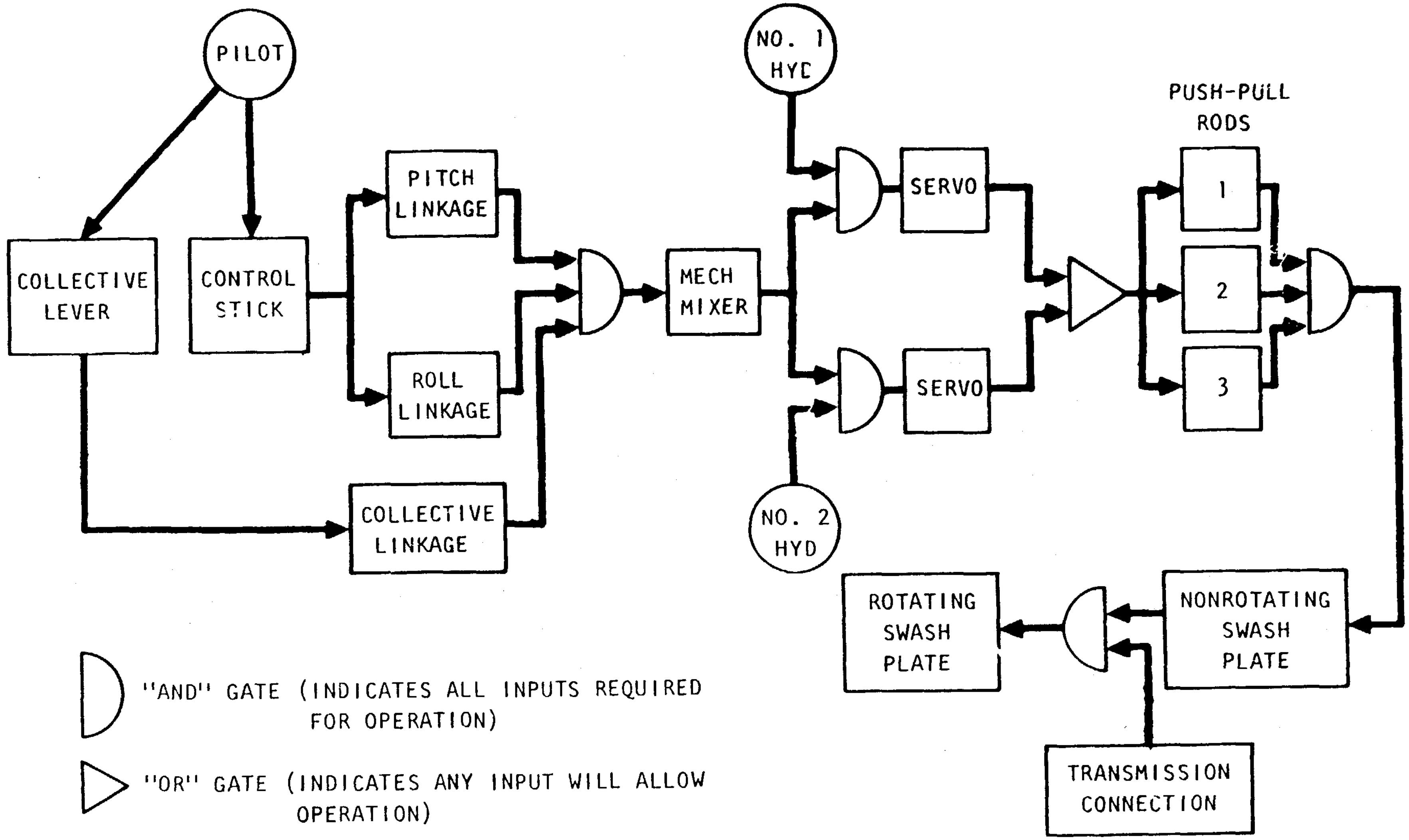


Figure 1. Flight Control System Functional Flow Diagram.

major contributors to vulnerability (engine, fuel, flight control, crew, and hydraulics) are identified as shown. By use of this type of format, the vulnerability of the systems can be examined and analyzed for their relationship to the expected angles of specific hostile small arms weapons. Comparison of the influence that different size, types, and striking velocities of projectiles have on the aircraft's vulnerability is also needed to identify potential areas of concern and to conduct encounter or mission survivability analyses.

Figure 3 illustrates the relationship of several sizes of armor-piercing incendiary (API) projectiles and one size of ball-type projectile, to the vulnerable areas associated with the attrition kill level. The impact velocities of each projectile also influence the measure of system vulnerability. As shown, the system is less vulnerable to the 7.62 mm ball projectile than it is to the API type.

Changes in vulnerable areas usually occur in "steps" when the threshold failure levels of more vulnerable areas are reached. The meaning of threshold failure level is that impact velocity of a specific size and type of projectile where penetration is achieved and causes a failure or malfunction that results in the specific level of kill being assessed.

With the foregoing vulnerability data, the most probable angles of small-arms fire can be compared to determine the importance of vulnerability aspects to the hostile threat systems. By analysis of the enemy weapon systems and aircraft combat mission flight paths, further refinements of vulnerability assessments can be made that will aid in determining the most beneficial survivability enhancement features that can be incorporated into the design. Figure 4 shows an example of the most probable angles of enemy small-arms fire for a hypotehtical aircraft. The angle α may vary with the size and type of ballistic threat, together with the altitude of the aircraft.

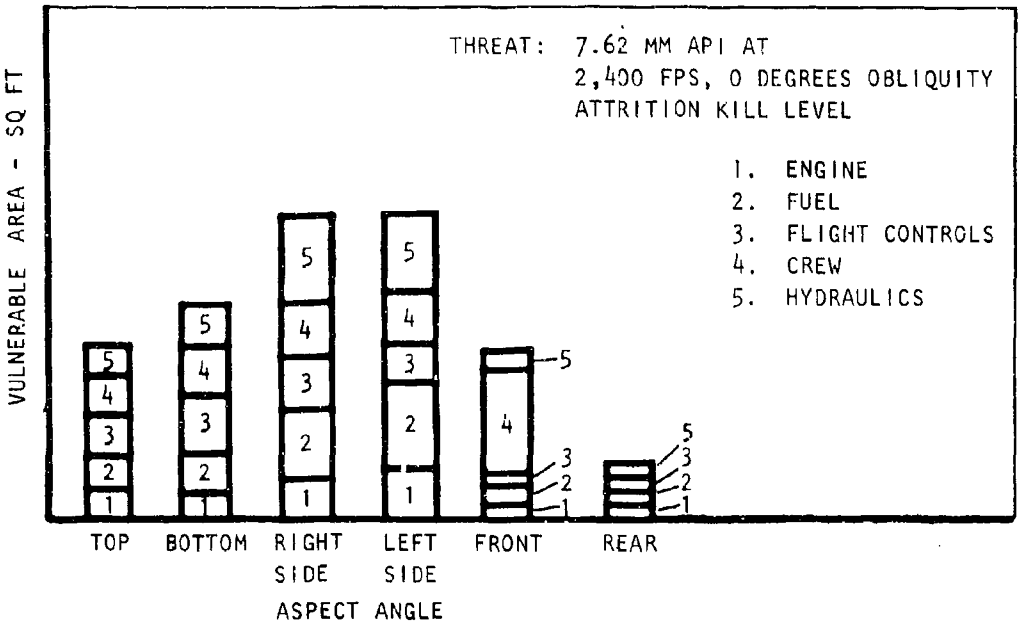


Figure 2. Major Aspect Angles.

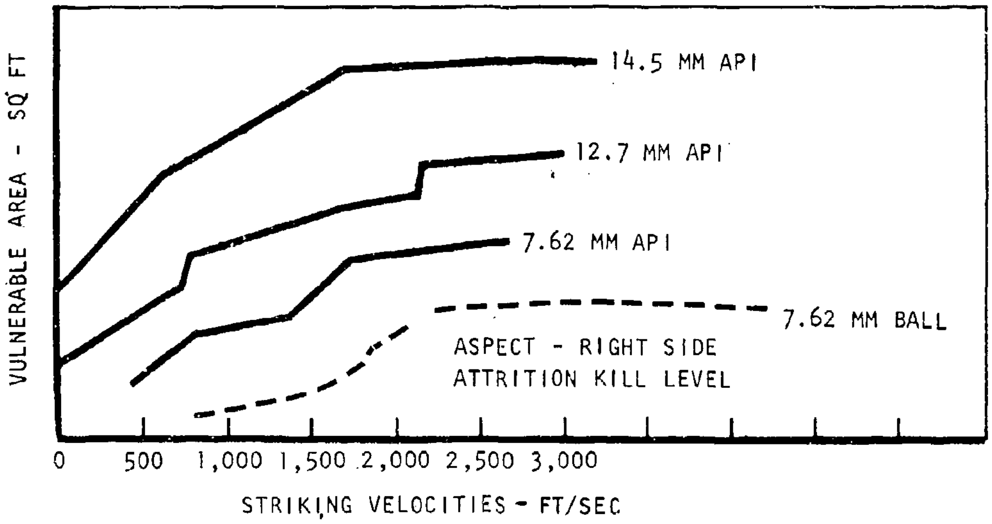
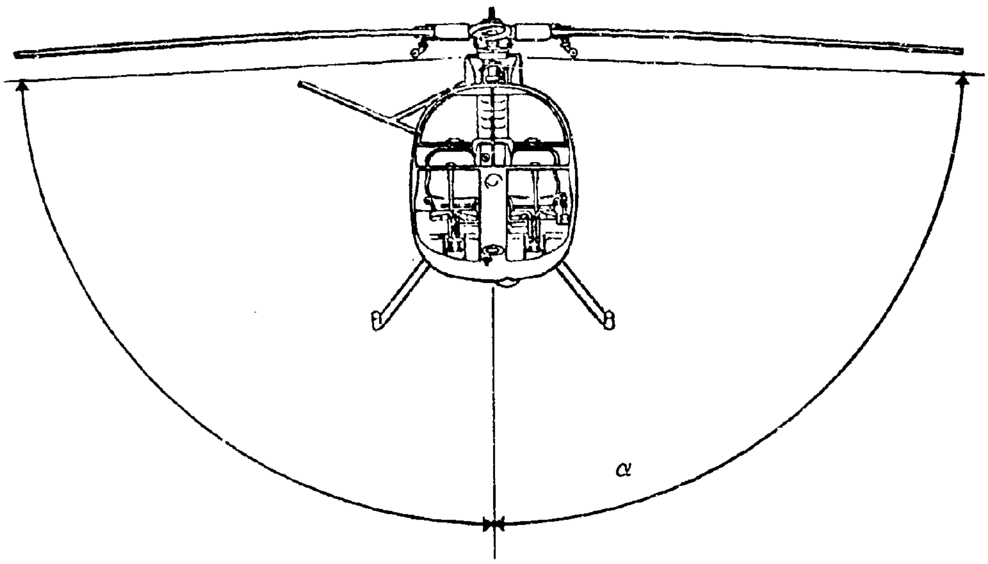


Figure 3. Vulnerable Area Tabulation Examples for Attrition Kill Level.



ANGLE α = MOST PROBABLE ANGLES OF
ENEMY SMALL-ARMS FIRE FOR
SPECIFIC ENCOUNTER CONDITION

Figure 4. Probable Angles of Enemy Small-Arms Fire.

CHAPTER 2

BALLISTIC THREAT CHARACTERISTICS

2.1 INTRODUCTION

This chapter addresses the types, sizes, and operating capabilities of hostile small-arms systems. It is presented in three basic sections. The first is a description of the general classifications and categories of weapons, the second contains a description of individual weapons, and the third contains information on the types of projectiles and their capabilities. These data are compiled to provide aircraft designers and survivability analysts with a centralized data source for their individual tasks. Only the basic information and summary of hostile weapons is presented in this chapter.[2] Detailed information is contained in Appendix I.

2.1.1 SMALL-ARMS DEFINITION

For the purpose of this publication, small arms are defined as weapons which fire projectiles up to and including 14.5 mm in size, in use by forces hostile to the United States. Currently, this definition limits the listing to weapons commonly furnished to troops of the Communist Bloc countries.

2.2 SMALL-ARMS SYSTEMS

2.2.1 GENERAL

Standard weapon calibers defined as small arms and available at Communist Bloc countries are:

- 7.62 mm
- 7.92 mm
- 12.7 mm
- 14.5 mm

Weapon sizes in the Communist Bloc countries are limited in the interest of standardization and logistical problems. The types of small-arms weapons available include:

- Hand held: pistols
- Shoulder fired: submachine guns, carbines, rifles, assault rifles
- Mounted: company machine guns, light machine guns, heavy machine guns, small-caliber antiaircraft machine guns

The weapon types and ammunition sizes pertinent to this guide are summarized in Table I. Pistols are excluded from this since they are few in relation to the rest of the small-arms weapons and considerably less effective. The 9-mm size weapons are also excluded since they have been phased out to minimize ammunition logistic requirements.

TABLE I. SMALL-ARMS WEAPONS AND SIZES

Type	7.62 mm	7.92 mm	12.7 mm	14.5 mm
Submachine Guns	X			
Carbines	X			
Assault rifles	X			
Company machine guns	X			
Light machine guns	X			
Heavy machine guns	X	X		
Heavy antiaircraft machine guns			X	X

The following paragraphs give a brief description of each type of small-arms weapon. The capabilities for each representative category type are summarized in Table II. This includes the weapon's weight, maximum effective range, practical rate-of-fire, ammunition type, magazine capacity, mount for firing, sighting type, and typical muzzle velocity.

TABLE II - SUMMARY OF SMALL-ARMS WEAPON CAPABILITIES

Weapon System	Weight Unloaded (lb)	Max. Effective* Range (meters)	Practical Rate of Fire	Operation Mode	Ammo Type	Magazine Capacity (rounds)	Mount for Firing	Sighting	Typical Muzzle Velocity (fps)
Submachine Guns									
7.62 mm type 50	8.0	200	150-200	Selective	B, BT	35	(Shoulder-fired)	Mech	1,908
7.62 mm 1943 (PPS)	7.5	200	120	Automatic	B, BT	35	(Shoulder-fired)	Mech	1,640
7.62 mm 1941 (PPSh)	9.75	300	120	Selective	B, BT	71	(Shoulder-fired)	Mech	1,650
Carbines (STD)									
7.62 mm M1944	8.6	500		Manual	B, BT API IT	5	(Shoulder-fired)	Mech	2,690
7.62 mm Type 53	8.6	500		Manual	B, BT API IT	5	(Shoulder-fired)	Mech	2,658
Assault Rifles (INT)									
7.62 mm AKM	6.93	500		Selective	B, BT API IT	30	(Shoulder-fired)	Mech	2,329
7.62 mm AK47	9.18	500		Selective	B, BT API IT	30	(Shoulder-fired)	Mech	2,329
Light Machine Gun (INT)									
7.62 mm RPK	10.8	500	150	Selective	B, BT API IT	75	Bipod	Mech	2,411
Light Machine Gun (STD)									
7.62 mm DPM	20.9	800	80	Automatic	B, BT API IT	47	Bipod	Mech	2,766
Company Machine Gun (STD)									
7.62 mm RP-46	29.75	1,000	230-250	Automatic	B, BT IT API, AP	250	Bipod	Mech	2,730
Heavy Machine Gun									
7.62 mm SGM	29.8	1,000		Automatic	B, BT IT API, AP	250	Tripod, Wheel Carriage	Mech	2,625
Heavy AA Machine Gun									
12.7 mm 38/46 DS sh	347**	1,000	80	Automatic	API-T API	50	Single ground	Mech	2,822
12.7 mm QUAD	1331**	1,000	80/gun	Automatic	API-T API	50/gun	Quad carriage	Mech	2,766
Heavy AAMG ZPU									
14.5 mm model ZPU-2	838**	Available as classified data in Volume II	150/gun	Automatic	API-T API	150/gun	Dual Wheeled and ground	Mech/Opt	3,281
14.5 mm model ZPU-4	4400**		150/gun	Automatic	API-T API	150/gun	Quad Wheeled and ground	Mech/Opt	3,281

B = ball; AP = armor piercing; I = incendiary; T = tracer
*Effective ground combat range is used where effective AA slant range is not applicable.
**Includes mount.

2.2.2 SUBMACHINE GUNS

Submachine guns use the same ammunition as 7.62-mm and 9.0-mm pistols, although tracer-type ammunition may also be used. These weapons, since they are heavier and shoulder fired, have two to four times the effective range of pistols. Typical 7.62-mm submachine guns include the 1941 Shpagin (PPSh), type 50, and 1943 (PPS). These are the only shoulder-fired weapons that use pistol ammunition. (Refer to Appendix I for details.)

All 7.62-mm weapons, with the exception of pistols, submachine guns, and heavy machine guns, are chambered to accept one of two 7.62 mm cartridge configurations - intermediate (INT) or standard (STD). The intermediate is somewhat smaller than the standard with respect to weight and is used with lighter 7.62-mm guns.

2.2.3 CARBINES

Carbines in general use are chambered for 7.62-mm intermediate or 7.62-mm standard ammunition. Those chambered for 7.62-mm intermediate include the SKS and type 56 carbines. Those chambered for 7.62-mm standard ammunition include the M1944 and the type 53 carbine. These weapons may be used against slow and low-flying aircraft. (Refer to Appendix I for details.)

2.2.4 ASSAULT RIFLES

Assault rifles, being designed for lightness and portability, are chambered only for the 7.62-mm intermediate ammunition. This weapon has a higher practical firing rate, due to larger size magazines. This is considered a threat to slow and low-flying aircraft. Models typical of this weapon are the AKM and AK-47. (Refer to Appendix I for details.)

2.2.5 LIGHT MACHINE GUNS

The lightest 7.62-mm mounted machine gun is chambered for the intermediate and standard ammunition. These guns are bipod-mounted and have a good practical rate of fire and are always a threat to slow and low-flying aircraft within range. Typical of this weapon are the RPD and RPK light machine guns using intermediate ammunition and the DP and DPM using standard ammunition. (Refer to Appendix I for details.)

2.2.6 COMPANY MACHINE GUNS

These guns may be heavier than the light machine guns and have a larger capacity as well. They are bipod-mounted guns. These guns are chambered for the 7.62-mm standard ammunition round. Typical weapons are the RP-46 and the Type 58. (Refer to Appendix I for details.)

2.2.7 HEAVY MACHINE GUN

This is a battalion-level gun, mounted on a tripod or a wheeled carriage and chambered for 7.62-mm standard ammunition. Typical is the SGM type which is detailed in Appendix I.

2.2.8 12.7 MM ANTIAIRCRAFT HEAVY MACHINE GUN

The antiaircraft function of this gun is becoming obsolete, although it is still used against aircraft by guerrilla and irregular forces. This weapon is effective against slow and low-flying aircraft. Details of two types are shown in Appendix I.

2.2.9 14.5-MM HEAVY ANTIAIRCRAFT MACHINE GUN

This weapon is a standard antiaircraft defense for Communist Bloc countries in single and multiple carriage. This weapon is quite effective against slow and low-flying aircraft and also effective against aircraft flying at moderate subsonic speeds. (Refer to Appendix I for details.)

2.3 PROJECTILES

2.3.1 GENERAL

The capability of a passive projectile to inflict damage or injury is based on the amount of kinetic energy it possesses and the effectiveness with which this energy is transmitted into the target. Methods to improve the passive projectile damage-inflicting capability include improvement of projectile penetration characteristics and reduction of impact breakup characteristics. Nonpassive methods of improving terminal damage effectiveness include (1) active incendiary interior elements to give the projectile fire-starting capability subsequent to complete penetration, and (2) high-explosive interior elements to give blast, thermal, and improved fragmentation effects at or slightly after impact (this technique requires some type of fuzing arrangement for activation). These latter methods are not pertinent to small-arms projectiles. One other nonpassive element is

the inclusion of tracer material at the rear of the projectile. The tracer element is a highly visible bright-burning material ignited by the burning of the propellant. Tracers are used for aiming and sighting by observation of the projectile trajectories.

2.3.2 SMALL-ARMS PROJECTILES

Designers use both passive and active (nonpassive) methods to improve small-arms projectile damage capability. Size limitations at present preclude the use of high-explosive fillers and fuzing mechanisms in small-arms projectiles. Thus, active small-arms projectiles are limited to incendiary and tracer fillers. The type of projectiles generally used in small arms are:

a. Ball (B) - a passive projectile with a relatively soft metal interior (core).

b. Armor-piercing (AP) - a passive projectile with a hard tough core which has a shape designed to maximize its penetrability.

c. Tracer (T) - an active bright-burning core, always used with a primary core, which may be either ball or armor-piercing material.

d. Incendiary (I) - a thermally active projectile filler used with a passive core, either ball or armor-piercing material. The active filler is located in front of the passive core. The passive core penetrates the exterior structure, driving and shattering the incendiary filler ahead into the interior of the target.

2.3.3 HOSTILE THREAT

Table III presents the types of projectiles in general use by forces that can be considered hostile. Figure 5 shows typical projectiles used by hostile forces.

2.4 PROJECTILE BALLISTICS

2.4.1 GENERAL

Small-arms projectiles are a threat to a target any time after ejection from the gun muzzle. The projectile reaches its maximum velocity and energy shortly after exit from the gun barrel. Small-arms muzzle velocities are generally measured at about 3 feet in front of the muzzle.

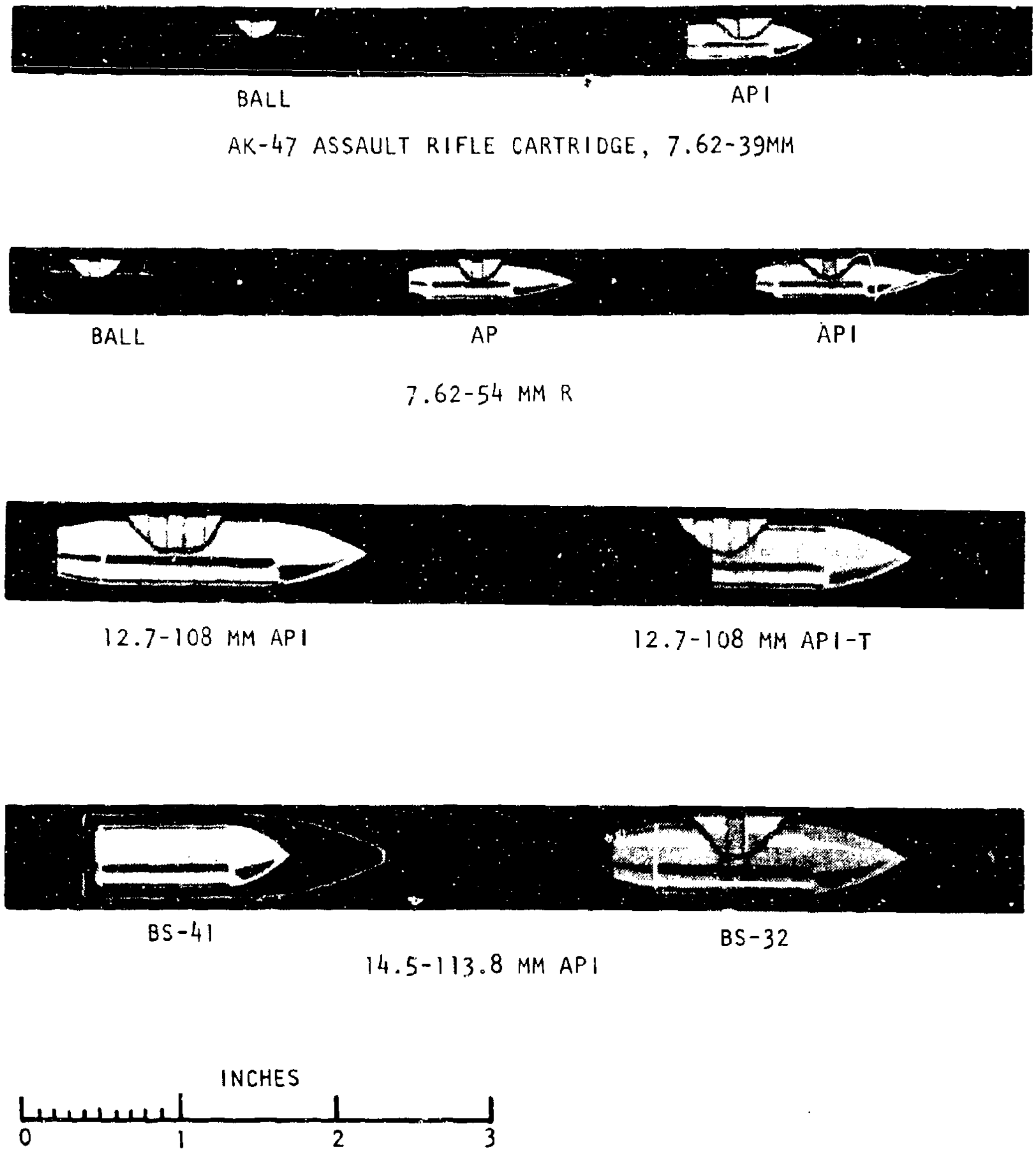


Figure 5. Typical Hostile Projectiles - Soviet and Chicom.

TABLE III. HOSTILE PROJECTILE SIZES AND TYPES					
Projectile	Projectile Type				
	B	BT	AP	API	API-T
7.62 mm	X	X	X	X	
7.92 mm	X				
12.7 mm				X	X
14.5 mm				X	X

For most threat analysis situations, the worst case (highest kinetic energy) is sufficient to define the threat. The worst-case situation can be determined using muzzle velocity and initial projectile mass where

$$KE = 1/2\, m\, V^2 = 1/2\, m\, (V_o + V_T)^2$$

m = initial projectile mass (slugs)

V_o = muzzle velocity (ft/sec)

V_T = target velocity (ft/sec)

A nomograph (Figure 6) may be used for determination of impact energy. This nomograph makes the necessary correction for the weight-to-mass conversion. Weight ranges for 7.62-mm, 12.7-mm, and 14.5-mm API projectiles are shown for reference. An example is shown for determining the impact energy (in foot-pounds) for a 14.5-mm API projectile. The penetrator weight of approximately 985 grains is located on the left-hand scale. With a straightedge, the impact velocity of 3,000 feet per second is aligned on the right-hand scale and a straight line scribed between them. Where the line intersects the middle scale is the impact energy value.

2.4.2 BALLISTIC RANGE DATA

In some design situations, knowledge of the worst case is not sufficient. For example, with an aircraft operating at appreciable distances or altitudes from hostile gun positions, significant reductions in projectile

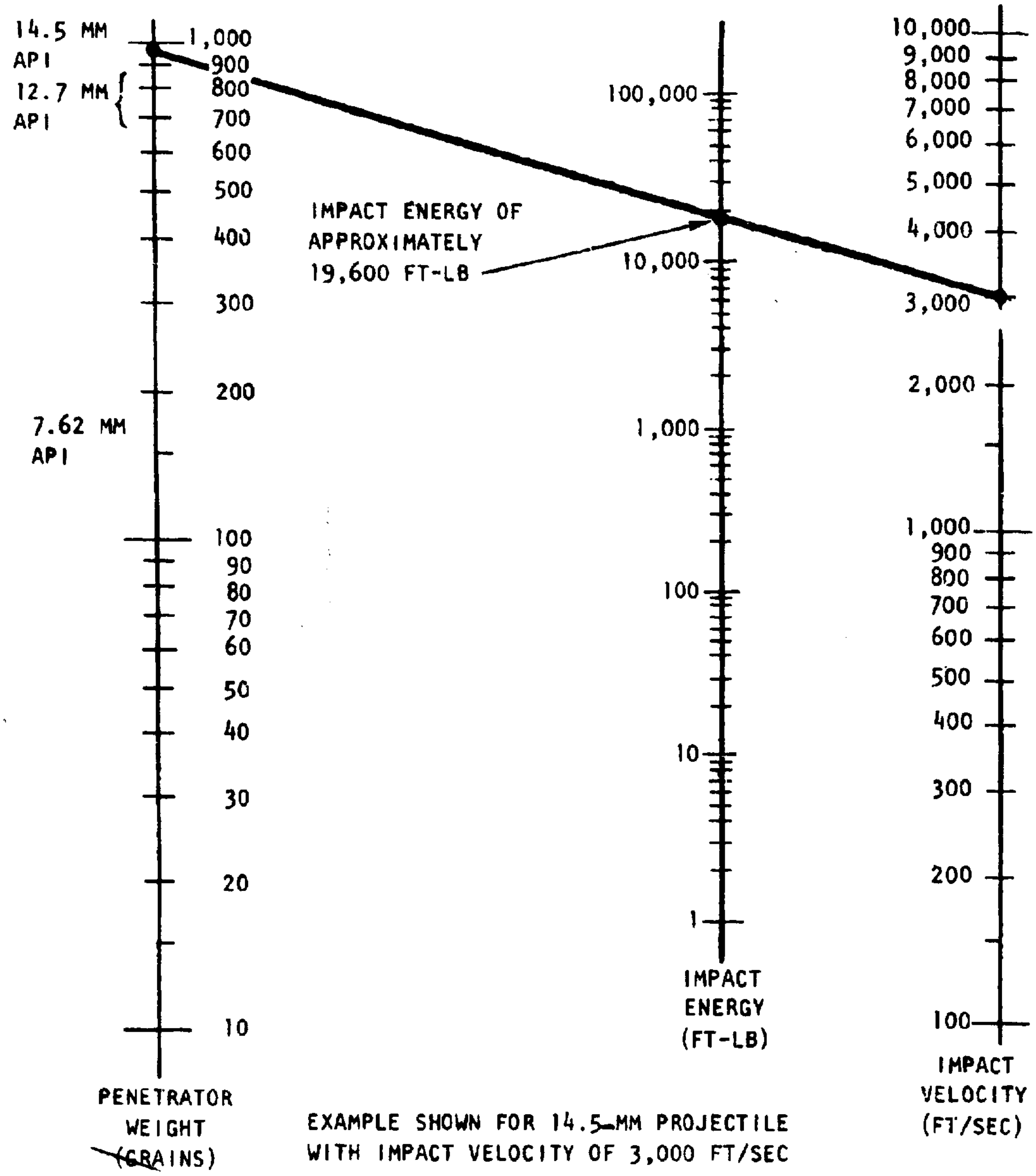


Figure 6. Penetrator Impact Energy Nomograph.

impact energies would be realized. In this instance, knowledge of projectile impact velocities for such ranges would be needed to determine the level of ballistic protection required.

In general, ballistic range data is generated from the solution of the equations of motion.[1]

$$m \frac{dv_x}{dt} = P_x = -D \cos \theta_{xa} = \frac{-d^2 P \cdot K_D \cdot \mu \cdot \mu_x}{1}$$

$$m \frac{dv_y}{dt} = P_y = -D \cos \theta_{ya-mg} = \frac{-d^2 P \cdot K_D \cdot \mu \cdot \mu_y - mg}{1}$$

$$m \frac{dv_z}{dt} = P_z = -D \cos \theta_{za} + L = \frac{-d^2 \cdot K_D \cdot u \cdot u_z}{1} + 2\pi mgp . \frac{K_L V_o u_x}{K_m n u^2}$$

where

m	= projectile mass in pounds
D	= drag force
d	= projectile diameter
ρ	= air density, lb/ft^3
K_D	= drag coefficient = D/d^2u^2
u	= projectile velocity with reference to air
u_x, u_y, u_z	= vector components of u
g	= acceleration due to gravity
P	= moment of inertia factor $A = mpd^2$
L	= crosswind force
M	= moment of overturning force
n	= twist in rifling in calibers/turn
V_o	= initial velocity - muzzle velocity

K_L = crosswind force coefficient $L/pd^2 u^2 \sin\delta$

K_m = moment coefficient - $m/pd^3 u^2 \sin\delta$

A = projectile axial moment of inertia

δ = angle between direction of motion and axis of projectile - angle of yaw

a = velocity of sound in air

The vector forces P_i of these equations are dependent on the vector forces operating on the projectile and include air resistance, gravity, yawing forces, and drag forces.

These equations have been simplified and rewritten, and applied to solutions of trajectories with idealized constraints (standard structure, atmosphere).

$$\frac{dv_x}{dt} = -\frac{\rho_o e^{-hy} F(v) \cdot v_x}{C}$$

$$\frac{dv_y}{dt} = -\frac{\rho_o e^{-hy} F(v) \cdot v_y}{C} - g$$

$$\frac{dv_z}{dt} = -\frac{\rho_o e^{-hy} F(v) \cdot v_z}{C} + \frac{Q(v) \cdot v_x}{C_L}$$

where

$$\rho = \rho_o e^{-hy} \quad w_x = w_y = w_z = 0$$

$$u_x = v_x \quad u_y = v_y \quad u_z = v_z$$

$$u^2 = v_x^2 + v_y^2 + v_z^2 = v^2$$

$$a = \text{constant}$$

ρ_o = standard air density, sea level

e = base of Napierian logarithms

h = density law factor = $\rho_o e^{-hy}$

y = altitude factor in density law

$v_x\ v_y\ v_z = u_x\ u_y\ u_z$ = projectile velocity components

$F(v)$ = drag function

$Q(v)$ = drift function

C = ballistic coefficient

C_L = drift coefficient $m/2\ gj$

i = ballistic form factor

j = drift factor

θ = angle of trajectory inclination to horizontal

The solutions to these equations have been computed and compiled in ballistic tables. Any constraints to the equations are noted as ballistic table conditions in those tables used.

These tables generally show a compiled solution, given θ_o, v_o, and C, for the following ballistic elements. An excerpt from a compact ballistic table is shown in Table IV. It is used to quickly determine one or more of the elements of the trajectory of a projectile for which θ_o, v_o, and C are given. For example, given an angle of trajectory of $\theta_o = 15°$ and an initial velocity of $v_o = 3{,}000$ feet per second, for a ballistic coefficient C = 4, the horizontal range is 15,657 yards.

- Horizontal range - X_w
- Time of flight - t_w
- Angle of fall - ω_w
- Striking velocity - v_w

These data may also be presented in graphical form as shown in Figures 7, 8, and 9.

TABLE IV. COMPACT BALLISTIC TABLE - RANGE IN YARDS FOR VARIOUS VALUES OF θ_o, v_o, AND C

	v_o ft/sec	C 2	4	6	8	10	12	14
$\theta_o = 15°$	1,000	4,105	4,534	4,713	4,816	4,882	4,927	4,961
	1,500	6,035	7,406	8,204	8,749	9,147	9,453	9,695
	2,000	7,640	10,163	11,853	13,106	14,061	14,807	15,409
	2,500	9,167	12,937	15,680	17,809	19,478	20,815	21,909
	3,000	10,603	15,657	19,548	22,675	25,189	27,237	28,939
$\theta_o = 30°$	1,000	6,383	7,365	7,799	8,047	8,209	8,321	8,405
	1,500	8,895	11,351	12,786	13,782	14,522	15,104	15,757
	2,000	10,756	14,721	17,391	19,431	21,075	22,438	23,591
	2,500	12,488	18,072	22,207	25,616	28,503	30,961	33,060
	3,000	14,132	21,436	27,283	32,403	36,862	40,672	43,949
$\theta_o = 45°$	1,000	7,038	8,305	8,865	9,186	9,393	9,537	9,645
	1,500	9.798	12,867	14,661	15,888	16,791	17,490	18,051
	2,000	11,761	16,617	19,874	22,314	24,234	25,803	
	2,500	13,595	20,384	25,398	29,427	32,793		
	3,000	15,359	24,288	31,472	37,715			

2.4.3 PROJECTILE BALLISTIC DATA

Ballistic trajectory data for hostile small-arms projectiles are Confidential and are contained in the classified Volume II of this report (USAAMRDL Technical Report 71-41B).[33] The data are presented in graphical form that illustrates the altitude and horizontal range capabilities for a number of initial angles of trajectories.[2]

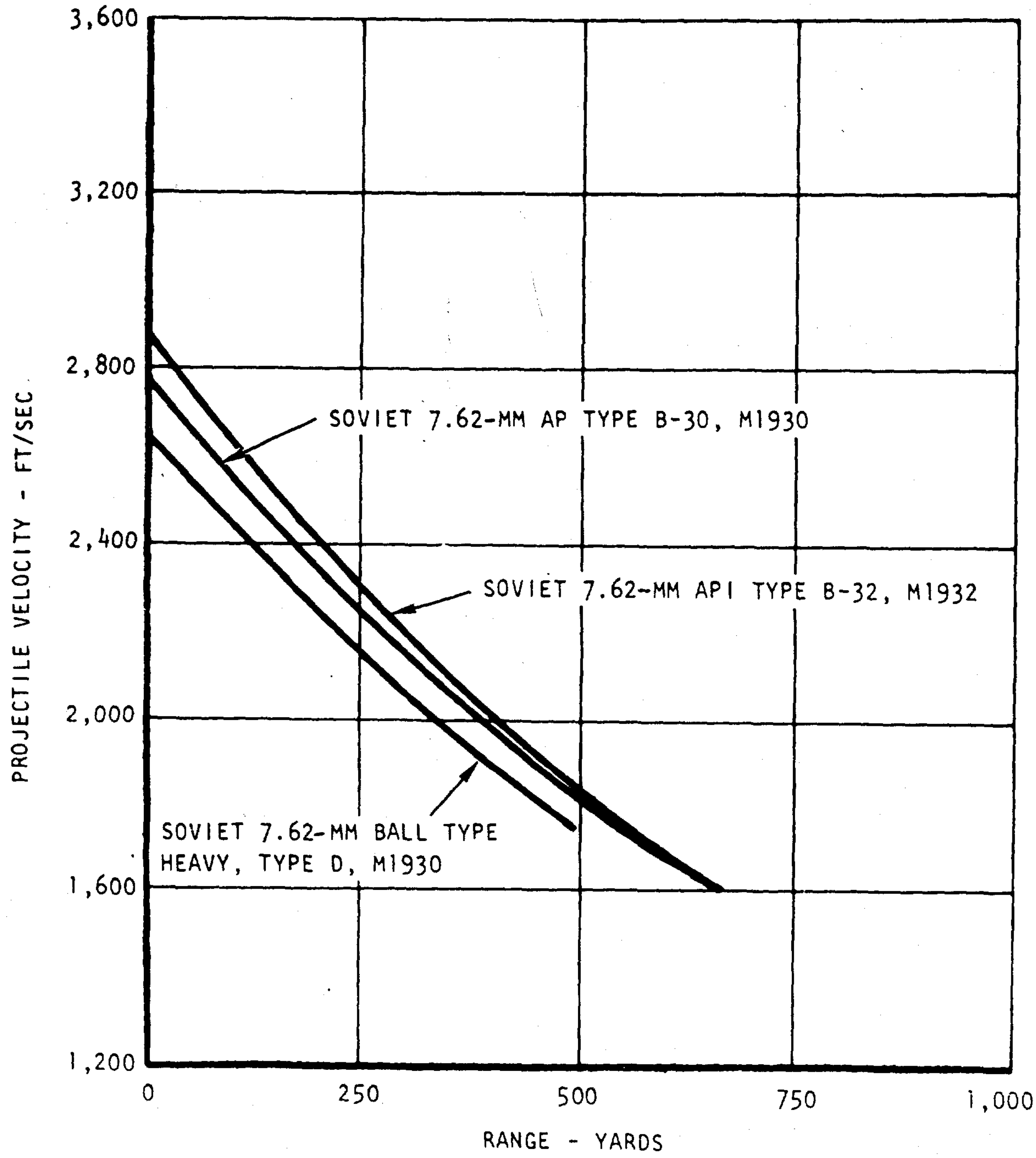


Figure 7. Range Versus Velocity Curves, Soviet 7.62-MM Projectiles.

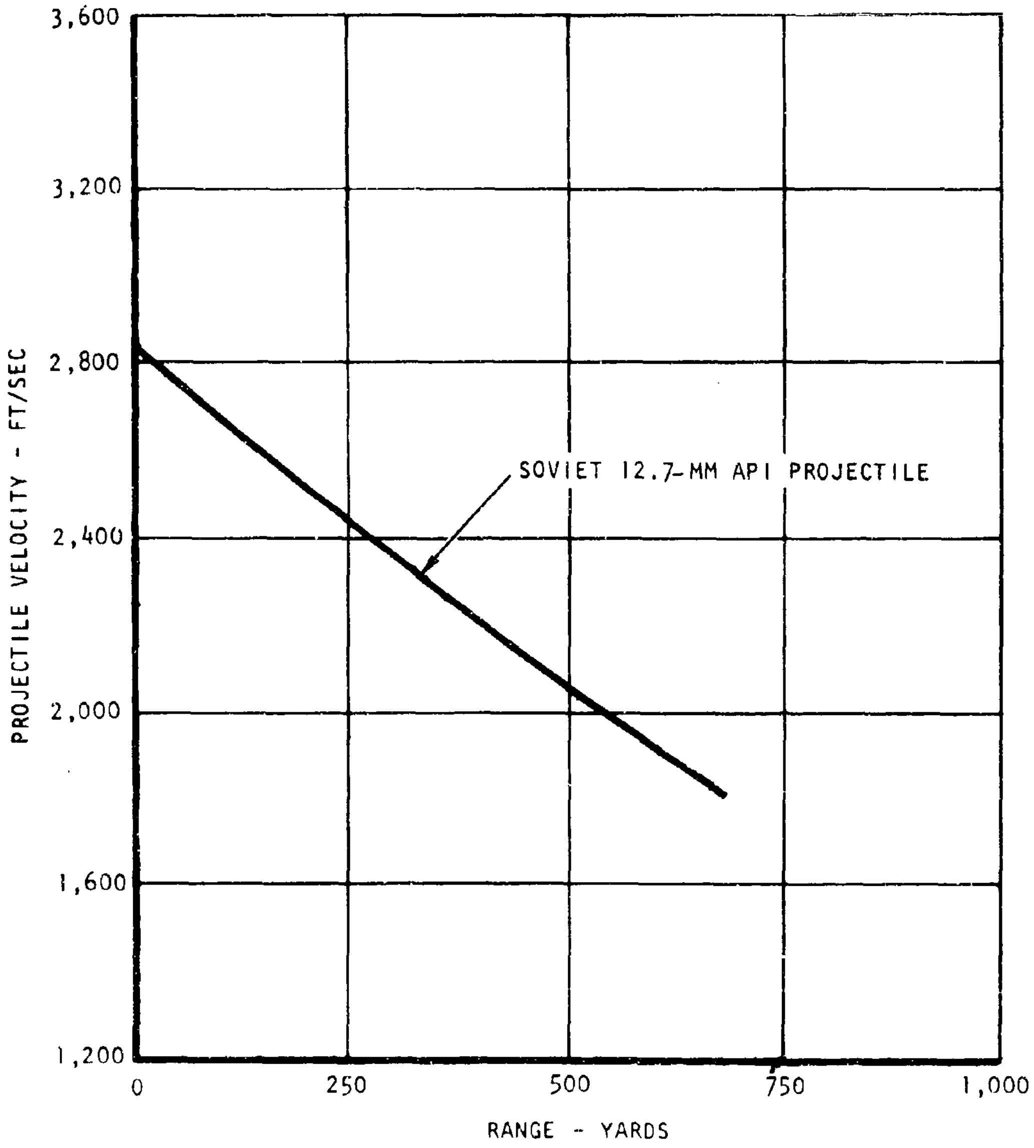


Figure 8. Range Versus Velocity Curve, Soviet 12.7-MM Projectiles.

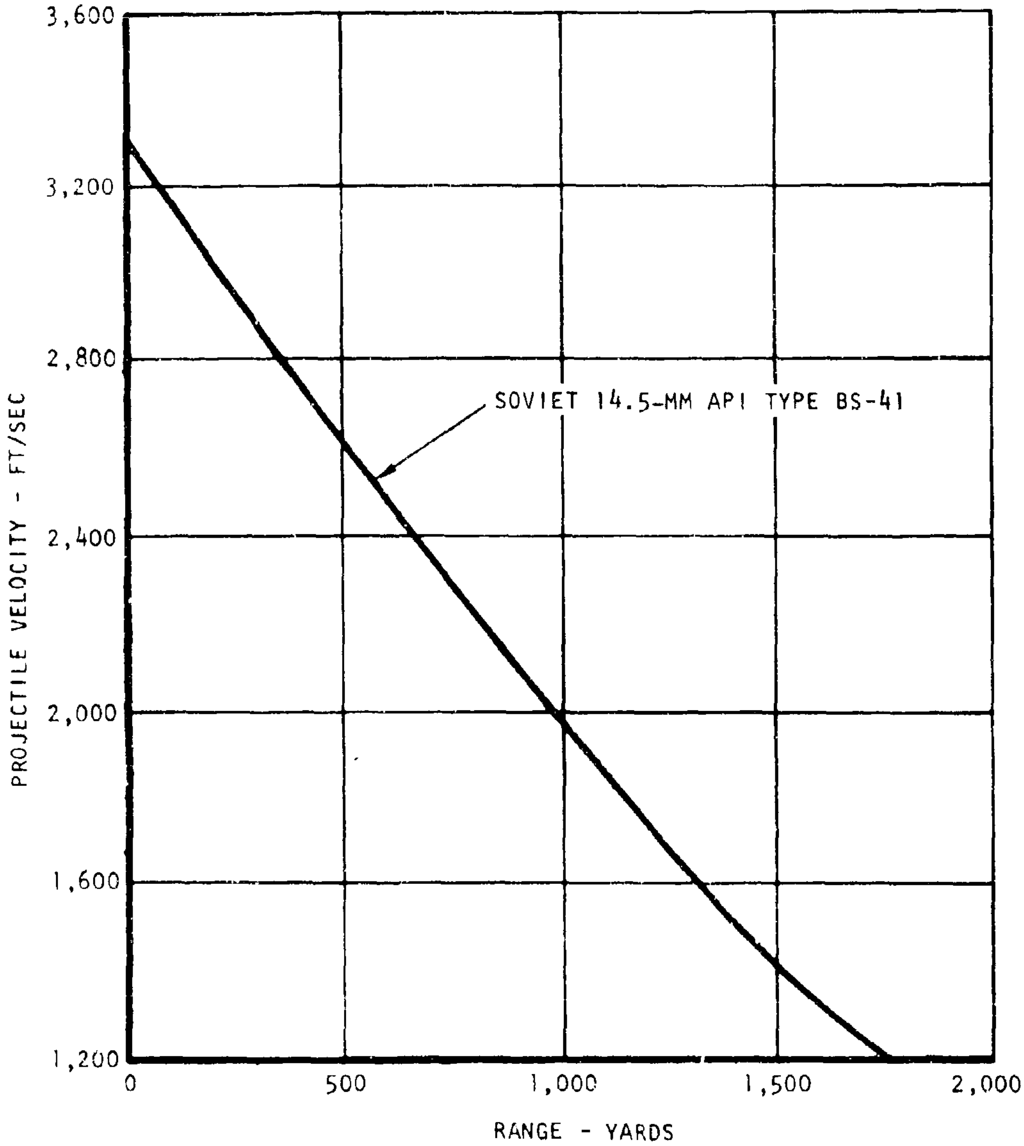


Figure 9. Range Versus Velocity Curve, Soviet 14.5-MM Projectile.

CHAPTER 3

GENERAL PROTECTION TECHNIQUES

3.1 INTRODUCTION

For all aircraft subsystem design disciplines, there exists a variety of general survivability enhancement techniques that may be applied. The designer must evaluate each to determine which are most suitable and effective for his individual subsystem and specific design requirements. Such evaluations must also consider the impact of each technique upon other design specialties such as maintainability, system safety, and reliability. These factors must be constantly evaluated during the design cycle to develop the most effective design configuration. Maintainability consideration is one of the most important areas in such design efforts since survivability enhancement techniques may not be compatible. The principles and techniques for maintainability are contained in AMCP 706-134, "Maintainability Guide for Design."[3]

When considering general survivability enhancement techniques for an aircraft design application, priority should be given to those techniques that provide the greatest benefits for the least penalties. For example, damage tolerance, redundancy, and fail-safe response design features will generally be more system/cost effective than the use of armor to obtain a given level of survivability against hostile small-arms fire. This chapter lists the general categories of techniques to the depth that is applicable for the majority of subsystems. Where more detailed information is applicable to one or a few specific design disciplines, it is included in the specific design areas contained in Chapter 4.

The techniques described in this chapter are:

- Minimized detection
- Redundancy/separation
- Isolation
- Damage tolerance/resistance
- Leakage suppression/control
- Fire/explosion suppression

- Fail-safe response
- Material selection
- Masking/armor

3.2 MINIMIZED DETECTION

3.2.1 INTRODUCTION

Generally, where the threat encounter is limited to small-arms fire, the only detection methods available to hostile forces will be the basic human aural and visual faculties with limited extended capability by use of binoculars. Thus, in this section, protection against the more sophisticated detection methods (i.e., low-light-level, infrared, and audio detectors) is not addressed.

Aural characteristics discernible by the ear are source direction, relative intensity, and frequency. Visual characteristics discernible by the eye include source direction, relative intensity, color (frequency), contrast, object shape, movement, and relative size. Sight and hearing generally complement one another in the detection role. Ability to view object shape and size gives the capability of determining dimension and range if familiar comparative size and range standards are available.

General methods of overcoming an observer's detection capability include:

a. Reduction of visible and/or audible signatures below the threshold values required for detection

b. Minimizing the contrast between the sensed object and its background

c. Degradation of the observer's sensing ability

d. Confusion of the observer's judgment by masking and/or biasing the relationships of detected parameters

All presently available means for detection minimization use the foregoing above methods, singly or in combination.[4-9]

Daytime and nighttime light conditions strongly influence the techniques that can be used to minimize visual detection for specific mission requirements.

Detectable aural and visual levels are generally modified by meteorological and atmospheric conditions.

3.2.2 VISUAL DETECTION FACTORS

Suppression or reduction of aircraft visual signatures is primarily a qualitative effort since its effectiveness must be determined empirically through tests. In order to incorporate minimized visual detection features into a design configuration, human capabilities and air vehicle operating conditions must be understood. This section addresses this subject along with specific methods that can be used as candidate methods of techniques for a given aircraft and its intended operational mission.

3.2.2.1 Sources of Visual Cues: Some sources of the visual cues presented to an observer include: a. Light reflecting from the exterior surfaces of the aircraft, b. Interior aircraft lights reflecting through windows/transparencies, c. Exterior lights, and d. Contrast between aircraft and background luminescence levels.

How well humans can see must be considered in determining the techniques that may be employed to minimize detection probabilities for specific operational conditions. Figure 10 shows experimental data for the minimum velocities, in minutes of arc per second, that can be detected for a range of luminance levels and viewing time in seconds. Figure 11 illustrates the extreme distance that a specific size object can be seen for a given meteorological range and contrast between the object and the sky. This can be determined by scribing a straight line between the contrast level and meteorological range. Where this line intersects the object size line, a vertically scribed line intersects the extreme sighting range value.

3.2.2.2 Visual Detection Minimization Methods: The following paragraphs give the general methods for minimizing visual detection of Army aircraft by hostile ground forces. Each aircraft configuration must be analyzed to determine the range of operational encounter conditions that will be experienced in order to identify the most beneficial enhancement features.

3.2.2.2.1 Engine Smoke Abatement: The engine and the fuel control must be designed to precluded the generation of visible smoke in combat operations. Engine smoke is detectable at considerable distances and provides enemy gunners with excellent tracking reference.

3.2.2.2.2 Camouflage: The basic principle of camouflage is to minimize the visual contrast of the aircraft and its background. The patterns and colors used for this are therefore highly dependent upon the terrain and seasonal changes in its background. There must be established for each

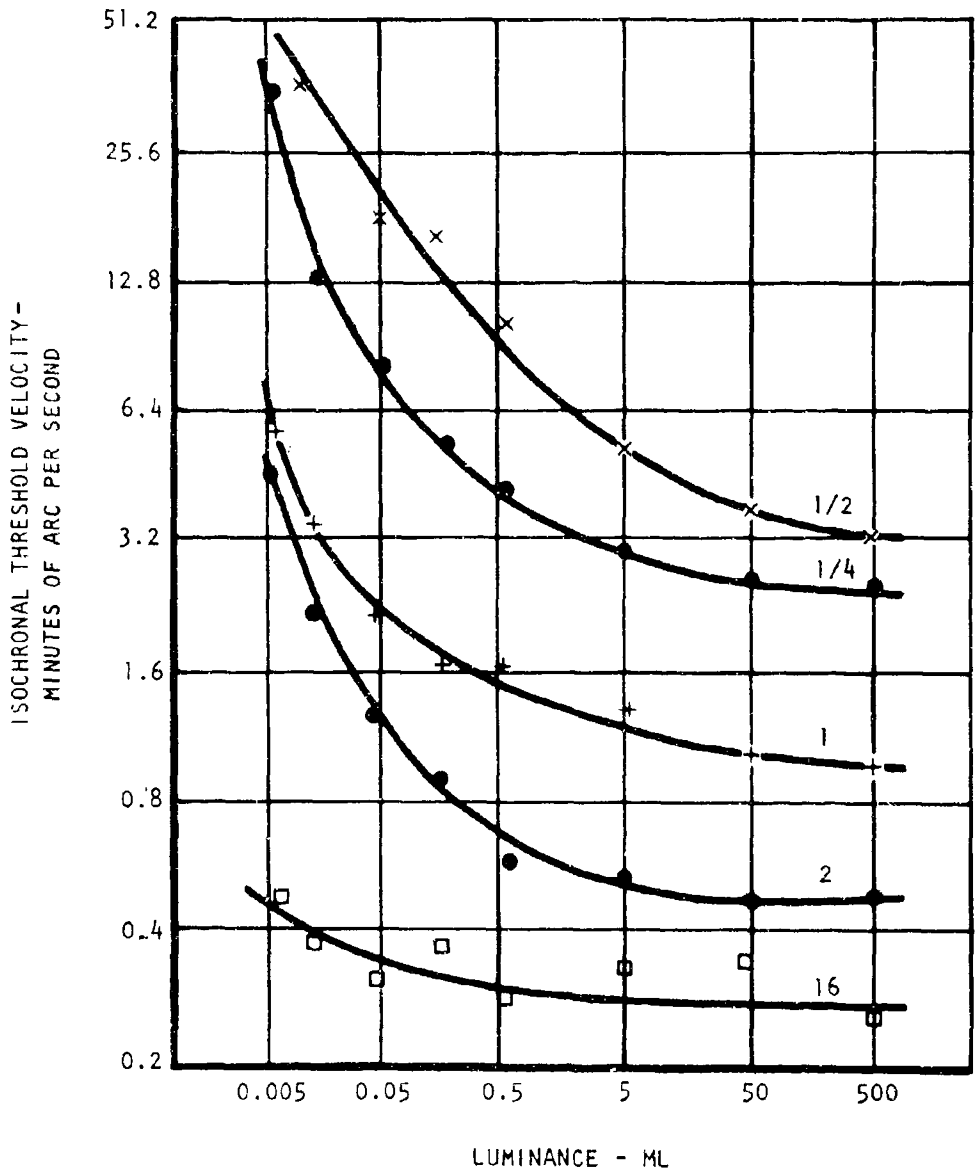


Figure 10. Minimum Detectible Velocity for a Constant Exposure Duration (Isochronal Threshold Velocity) as a Function of Luminance For Different Exposure Durations.

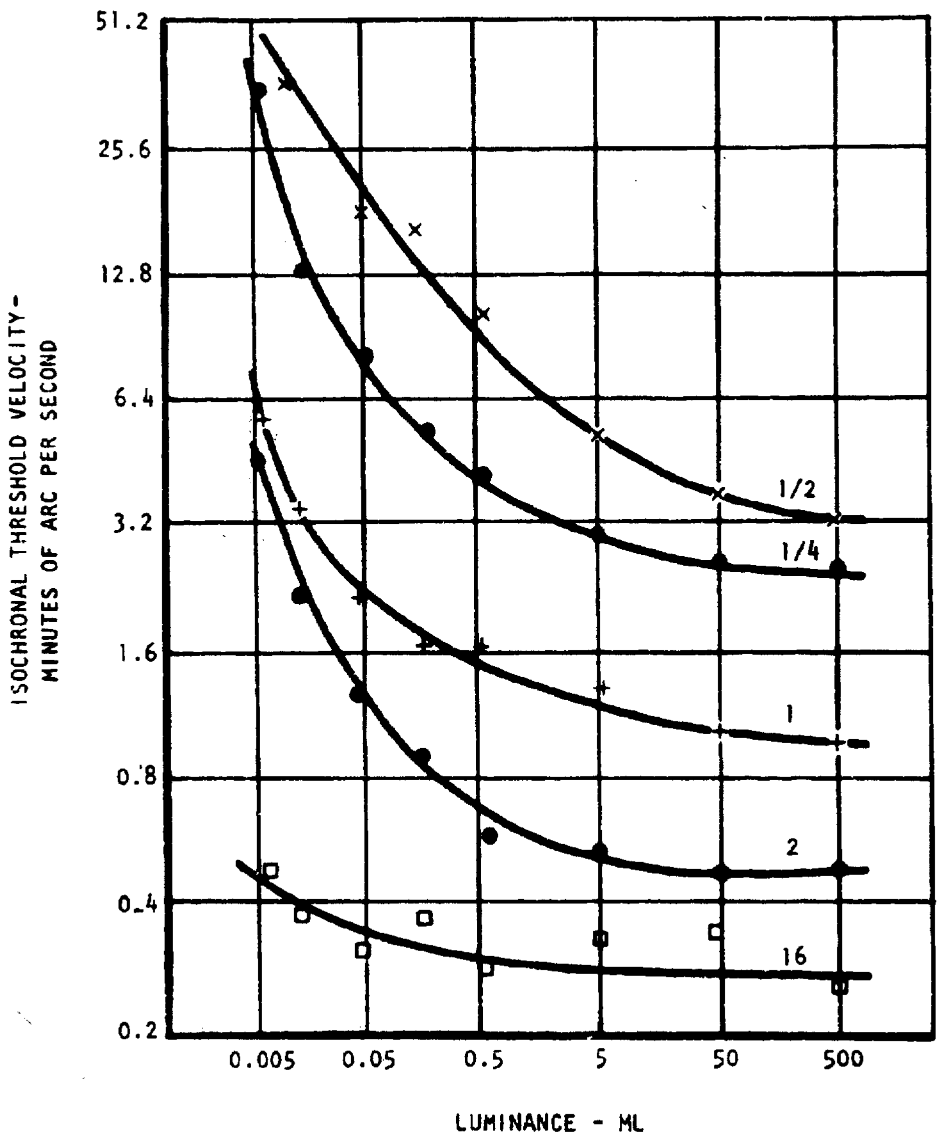


Figure 10. Minimum Detectible Velocity for a Constant Exposure Duration (Isochronal Threshold Velocity) as a Function of Luminance For Different Exposure Durations.

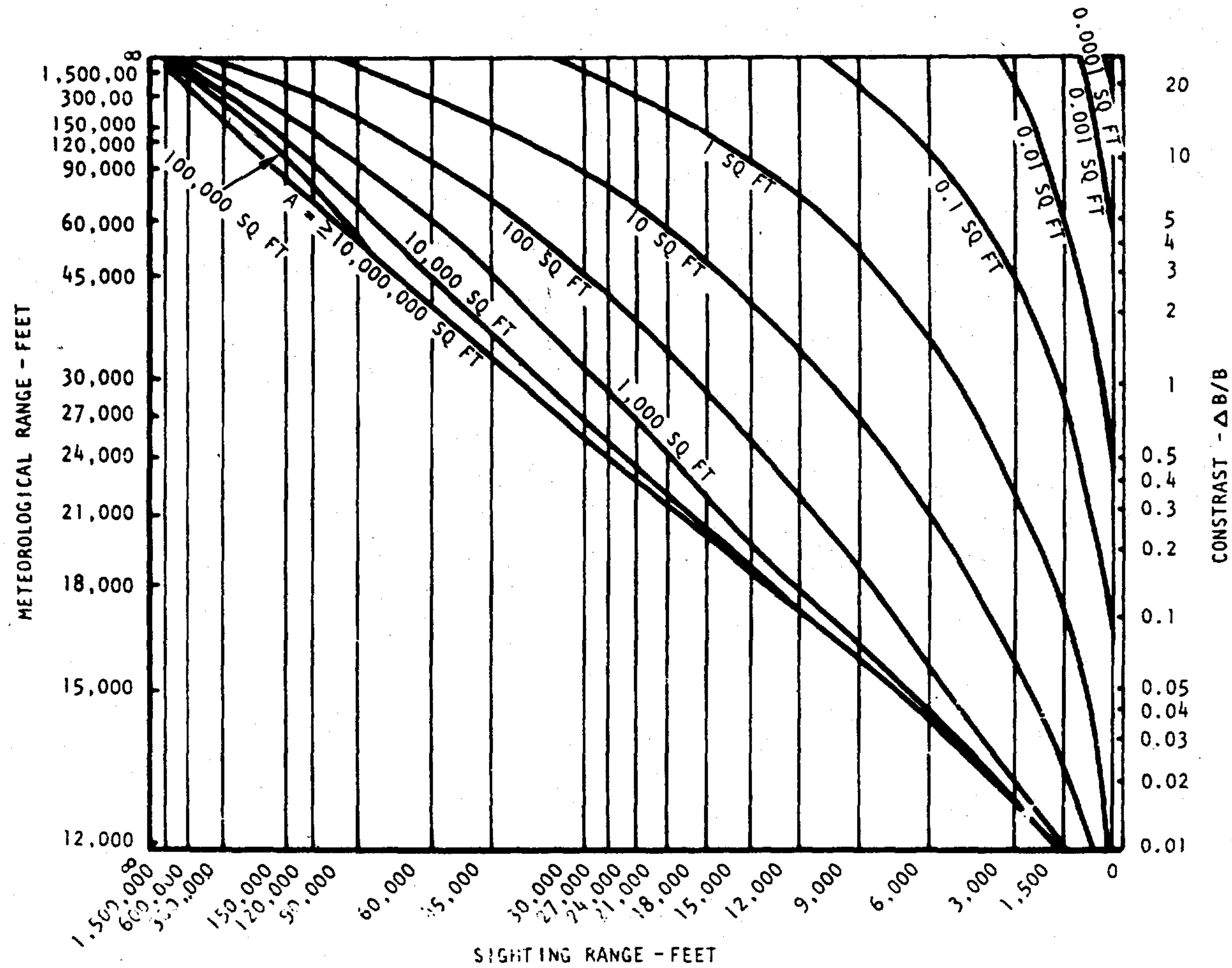


Figure 11. Visual Range in Natural Daylight.

specific application. There are, however, some general techniques and features that can be considered in the design. Transparencies (windows, canopies, etc) are generally highly reflective and provide strong visual clues to an observer. Consideration should be given to minimizing the amount of transparencies in those areas where sunlight or moonlight would likely be reflected from their surfaces to the ground. Temporary camouflage coverings or paint may be used to mask those transparencies not essential for specific missions.

Helicopter rotor heads have been found to be a significant source of reflected light as well. Consideration should be given to finishes that will minimize or subdue such reflective surfaces. Rotor blade tip markings also provide a degree of visual clues, but elimination or muting of such markings must be evaluated closely with personnel safety factors.

Standard bright identification markings and olive drab paint with a glossy finish are also reflective and are visible for a considerable distance both in sunlight and in moonlight. Lusterless camouflage paint should be used for the overall aircraft, with low-contrast paints for the necessary aircraft markings. Research has also indicated that well chosen simple camouflage patterns are more effective than poorly chosen complex patterns.

3.2.2.2.3 Optical Effects: Research has been conducted to investigate methods of producing optical illusions and delusions to affect the capability of an enemy gunner to adequately track the aircraft with his weapon.[5] A number of techniques have been used that may prove useful for specific applications. Data on these are, for the most part, classified and are mentioned here as candidate systems for individual investigation.

A moire pattern is an optical illusion that changes pattern rapidly with small changes in viewing angle. This feature can be highly disruptive to visual aiming by creating an illusion of rapid change of apparent speed and direction of the aircraft.

Widely separated flickering lights installed on aircraft have been investigated as means of distracting visual tracking accuracy for combat situations where the aircraft is well within visual acquisition range. Tests have indicated that appreciable benefit can be obtained with such a system.

"Yehudi" lighting systems[6] have also been researched as a means of lighting the underside of an aircraft so that it matches the brightness of the sky background. This method is useful only for aircraft at altitudes higher than the range of most small-arms weapons and is bulky and expensive. It is mentioned only for consideration in highly specialized mission concepts, such as higher altitude reconnaissance, where such protection could be effective.

3.2.2.2.4 Aircraft Lighting Systems: Nighttime combat operations are a special case where the effects of the aircraft's interior and exterior lighting systems must be considered as major sources of potential visual clues to enemy ground forces. Exterior lights should be masked from ground angles to the greatest degree practical while providing adequate safety for formation flying. The capability of anticollision light installations to reflect moonlight or other light sources when not in operation should also be considered to minimize such occurrences.

Interior instrument lighting systems must also be considered as potential sources of light visible from the ground. Tests have indicated that this factor can be significant in visual detection of an aircraft. Care should be exercised to minimize the direction and intensity of instrument lighting for combat missions and to minimize the interior reflective surfaces of the cockpit.[92]

3.2.2.2.5 Engine Exhaust Glow: When viewed directly, the exhaust glow of turbine engines can be seen readily at nighttime. For aircraft with primary missions at night, consideration should be given early in the design process to the probable viewing angles and methods of masking each engine glow from the enemy.

3.2.3 AURAL DETECTION FACTORS

3.2.3.1 Sources of Noise: The sources of noise from an aircraft are:

- Propeller or rotor (rotational and vortex)
- Engine exhaust (combustion noise)
- Aerodynamics (turbulence of boundary layer wake)
- Engine air induction and mechanical (piston slap, gearing, transmissions)
- Induced airframe panel vibration (from aerodynamics and engine)
- Auxiliary power systems

To determine the allowable sound levels and frequencies for a particular design configuration, human detection capability must be considered. This is dependent upon a number of variables including loudness levels, relative humidity, sound absorptivity of a given terrain, masking noises, and the sensitivity of the human ear. Figure 12 provides data on the sensitivity of the ear as a function of level above threshold and frequency. Figure 13

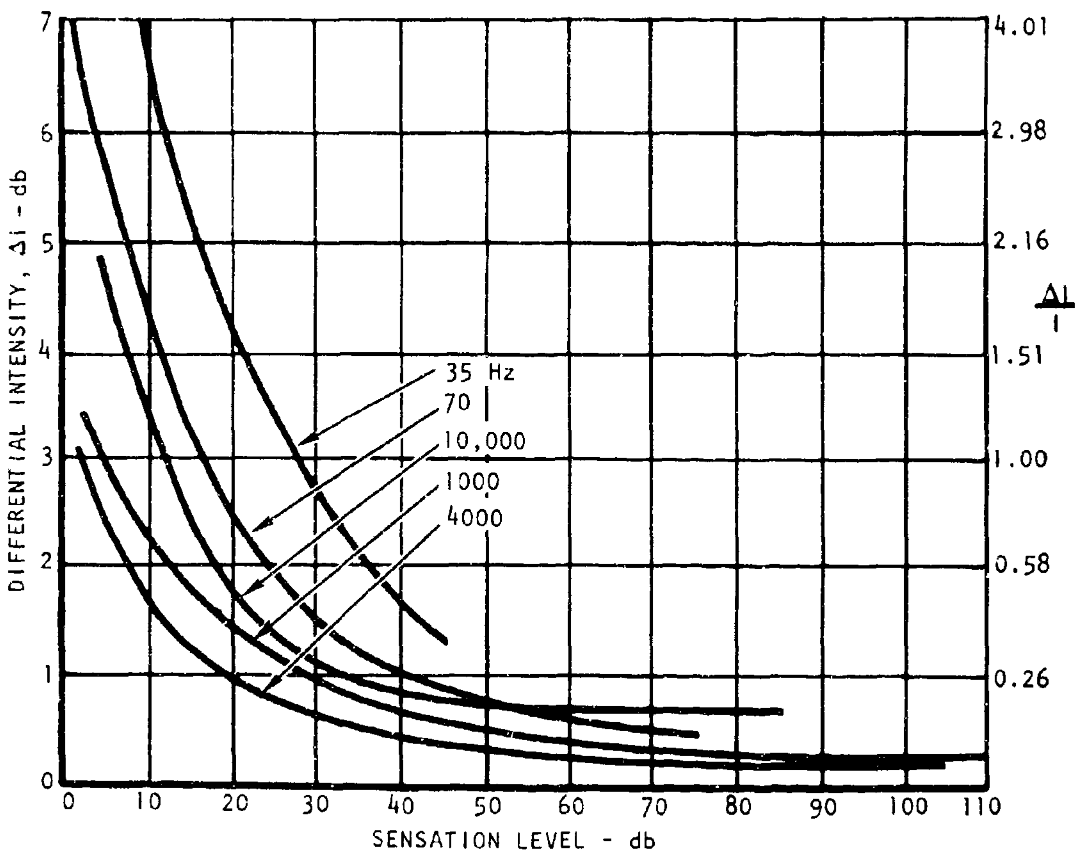


Figure 12. Sensitivity of the Ear as a function of Level Above Threshold and Frequency.

provides data on free-field equal-loudness contours for pure tones as a function of sound frequencies. Figure 14 provides data on sound attenuation versus relative humidity. Prediction of sound levels generated by specific aircraft components (i.e., rotor blades, propellers, transmissions, engines, etc) is dependent upon detail design features and operational parameters. The references listed for this subject contain detailed methodologies and data that can be used for individual analyses. Those listed should be considered as general data sources since there are many additional areas of information that are more specific in nature.

3.2.3.2 Noise Suppression Techniques: Noise can be suppressed through the following techniques:

- Design of propeller/rotor to minimize rotational and vortex vibrational amplitude (quiet operation)
- Design of exhaust systems to suppress hot gas noise
- Improvement in aerodynamic laminar flow characteristics around the airframe
- Use of quiet power train systems to replace conventional gearing, i.e., "V" belts, quiet gearing
- Operation of engine at reduced power

3.3 REDUNDANCY/SEPARATION

One of the basic ways to minimize aircraft losses is to provide duplicate or redundant systems to perform essential functions. This technique is also used for safety and reliability reasons. For survivability against hostile ballistic weapons, however, consideration must be given to adequate separation and mutual masking of redundant systems to minimize or prevent failure or malfunctions from single or multiple hits from a given direction. All major subsystems may use this technique. For example, multiple engines, fuel sump tanks, and control linkages provide redundant systems that permit the aircraft to function when one system element has ceased to function after a projectile impact. The separation portion of this technique must be carefully evaluated for each application to obtain the most beneficial amount of natural masking from structure and noncritical aircraft equipment. Masking can minimize or eliminate the need for parasitic armor that may otherwise be required to provide an acceptable level of survivability. The designer must consider not only the response of the system to the projectile impact, but also the secondary hazards that may also be initiated. These include fire, explosion, release of toxic or corrosive materials, spallation, and malfunction of related subsystems.

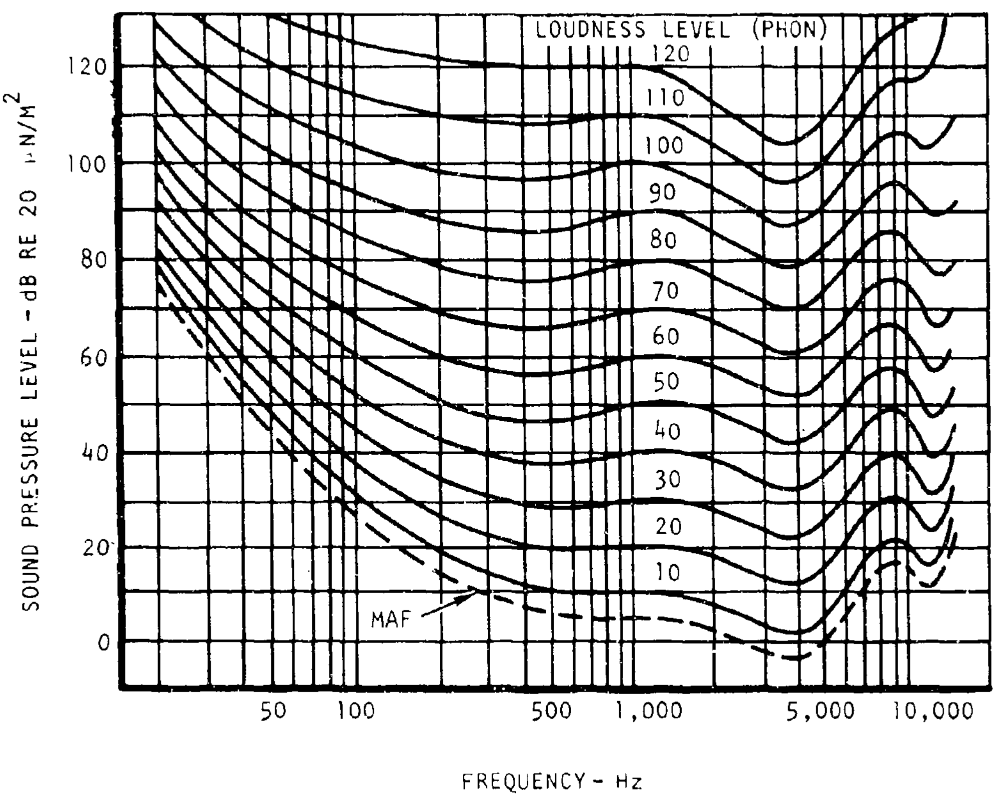


Figure 13. Free-Field Equal-Loudness Contours for Pure Tones (Observer Facing Source).

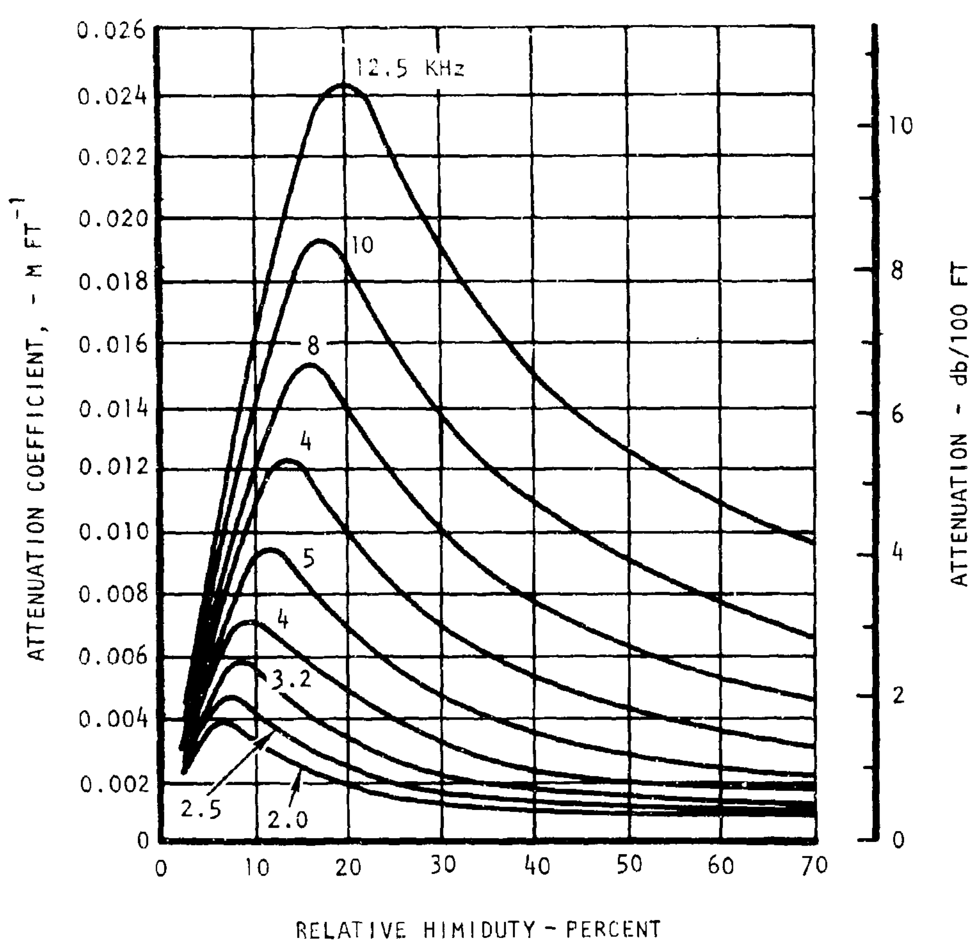


Figure 14. Sound Attenuation Versus Relative Humidity.

3.4 ISOLATION

In many instances, survivability of an aircraft can be increased by isolating a sensitive essential subsystem from areas of potential hazards that may readily be generated by a ballistic impact. Conversely, isolation of potentially hazardous materials such as fuel, munitions, oxygen, and high-pressure components in areas of least sensitivity should also be considered. In the first case, each subsystem should be examined to determine its most sensitive elements and the types of conditions that may cause it to fail, malfunction, or create a hazardous condition due to ballistic-impact-induced response. For example, flight control hydraulic lines should be isolated from areas where high-temperature gases would be liberated by ballistic damage. For the second case, fuel, lubrication, and hydraulic systems should be located in areas where leakage or vapors caused by projectile damage will not readily propagate to high-temperature ignition sources.

3.5 DAMAGE TOLERANCE/RESISTANCE

Two basic techniques have been developed to limit and/or minimize the primary and secondary damage mechanisms that can be generated by small-arms projectile impacts. Damage tolerance is an application of design techniques to construct essential structure and components in a manner to accept a degree of mechanical damage without impairing their capability to perform their functions. This is accomplished by providing redundant load paths, high-fracture-toughness materials, large-diameter and thin wall control rods, nonmetallic bellcranks and cable sectors, and high-temperature tolerance features. The majority of specific applications of this technique are contained in the structure, flight control, and fluid power design sections. It is one of the first techniques that should be considered in the design process since it can provide a significant degree of survivability for the least weight and cost penalties.

Ballistic resistance is a design technique to defeat the projectile's capability to penetrate the component by material selection and construction features. This can be illustrated most easily by the example of a current research effort to construct a damage-resistant transmission oil sump from dual-hardness steel armor material. It provides ballistic protection to the unit while acting as integral armor. Detailed examples of such techniques are contained in the appropriate subsystem design sections.

3.6 LEAKAGE SUPPRESSION/CONTROL

One of the most significant hazards that can be initiated by small-arms fire is the liberation of flammable, toxic, or corrosive fluids that are

used for the operation of military aircraft. There are two basic techniques that can be used to prevent or minimize dangerous consequences that can develop from ballistic impact: leakage suppression and leakage control.

Leakage suppression is a technique that uses self-sealing materials designed to accept a degree of ballistic damage and seal the damaged area with little or no leakage from the fluid container. This serves two basic purposes: (1) the fluid is retained for its intended use, and (2) the liberation of the fluid to areas where fire, toxic products, smoke, or corrosive reactions may be generated that would endanger the crew or operation of essential subsystems is suppressed.

Leakage control is a technique that may be used to handle and direct liberated fluids or vapors in such a manner that danger to the aircraft and crew is minimized. This technique includes sealing of sensitive or ignition-producing areas, drainage provisions, flow diverters, and venting features.

3.7 FIRE/EXPLOSION SUPPRESSION

Fires and/or explosions are serious threats to aircraft survival. They can be initiated by direct or secondary small-arms weapon effects. Each is the result of a combustion process where three basic elements are present: oxygen, flammable material, and an ignition source. An explosion is a specific form of a fire where rapid burning of flammable vapors causes high gas pressures to be generated within a confined space. Suppression or prevention of fires or explosions requires either prevention of ignition or suppression of the flame-front propagation once ignition has occurred. For flammable fluids, such as jet fuel, hydraulic oil, and lubricating oil, ignition can be prevented by techniques that do not permit the ratio of fluid vapor and air, that will support combustion, to occur. Where there is excessive air in ratio to fluid vapor, an overly lean condition is said to exist. Where the ratio of fluid to air exceeds the combustion limits, an overly rich condition is present. Forced venting of leakage-potential areas is another method that can be used to remove combustible fluids and vapors so that an overly lean condition exists. Minimizing the spaces available for fire acts as a suppression technique when it will hamper flame propagation. Inerting vapor areas within fuel containers is an effective means of preventing fires and/or explosions. The use of a non-combustible gas, such as nitrogen, is one such technique. The use of reticulated (open pore) foam is a recently developed technique. It acts as a three-dimensional "screen" that prevents propagation of a flame front. For void areas external to fuel tanks, sponge-type plastic foam may be used to prevent ignition or propagation of fuel fires. Another technique is the use of a fire detection and activated suppression system. A sensor

detects the ignition of the material within an area and transmits a signal to actuate the suppression device which, in turn, forcibly applies suppression material in time to prevent propagation of the flame front before it can develop into a fire and/or explosion. Details on the techniques described herein are contained in the fuel system section, since fuel systems constitute the largest portion of flammable materials in military aircraft.

3.8 FAIL-SAFE RESPONSE

Once the vulnerable subsystems and their components have been identified, their response to small-arms weapon effects must be analyzed. This analysis should examine the types and extent of damage that could be experienced and should consider methods of preventing or minimizing subsequent unsafe or hazardous conditions. This is the basic objective of fail-safe response techniques as applied to survivability. This analysis may be integrated with reliability and system failure mode and effects analysis where similar factors are considered. The criteria for fail-safe response are similar for each of these specialties, with the major difference being the cause of initial failure. For survivability, it is the primary or secondary weapon effects; for reliability, it is material failure; and, for safety, it is a nonhostile, hazardous environment.

An example of fail-safe response is the incorporation of an engine fuel control that will automatically position itself to a predetermined power setting if the throttle control linkage is severed. This technique can be applied to all subsystems. It is a technique to which each designer can apply his knowledge and ingenuity in providing fail-safe features for the least penalties.

Other examples of this technique include:

- The design of hydraulic accumulators that use high-pressure gas charging, with pressure limiting valves or blowout plugs that will prevent explosive desintegration of the gas pressure section when exposed to fire or high temperatures.

- The design of essential gearboxes and bearings to operate for extended periods when loss of lubrication has been experienced

- The design of multiple-load-path structure which provides fail-safe protection by preventing catastrophic failure when a load path is severed or severely damaged

3.9 MATERIAL SELECTION

The choice of construction or system operating media materials can have a significant influence in minimizing an aircraft's vulnerability to small-arms weapon effects. This consideration must be made early in the design effort in order to take advantage of such benefits. For structural elements and subsystem components that must retain their load-carrying integrity, high fracture toughness materials should be selected. This is necessary to prevent or limit crack propagation following damage from a projectile impact. Selection of transparency materials should be made to prevent or minimize shattering, spallation, and/or loss of essential visibility for the crew. Other considerations may be the selection of high-temperature tolerant materials in areas where the component or structure may be exposed to fire or hot gas "torching" as a result of small-arms projectile hits. Within the crew areas, nonflammable, nontoxic, and non-smoke-producing materials should be selected to minimize secondary hazards from ballistic threat damage.

3.10 MASKING/ARMOR

3.10.1 INTRODUCTION

The protection of aircraft personnel and flight/mission essential components, when exposed to hostile gunfire, is vital. Reduction of the effects of small-arms projectile impacts on the aircraft is a way to enhance survivability. This can be done by a combination of methods, including natural masking, redundancy, separation, isolation, damage tolerance/resistance, leakage suppression, minimized detection, and the use of integral or parasitic armor if still necessary. How these methods can be used, either independently or in combination, must be considered in the initial design effort in order to eliminate the need or to minimize the amount of armor required to supplement the other methods that can be used. Only a limited amount of data is available on the capability of aircraft construction material and component damage tolerance/resistance, minimized detection, etc, to defeat ballistic projectiles in contrast to an abundance of data and information on lightweight armor material capabilities to defeat projectiles.[10-27]

3.10.2 NATURAL MASKING

The structure, consumables, and components of an aircraft system can act as a barrier for personnel or flight/mission-essential components against small-arms projectiles. The technique of natural masking is to arrange those elements in a fashion to gain the most protection with the least penalties and to incorporate the protection with the rest of the design

requirements. For example, providing heavy structure around the crew station for crashworthiness considerations can, at the same time, provide some natural masking against small-arms projectiles from those directions that are likely to be experienced under combat operations. Similarly, less essential or vulnerable components or consumables can be placed to eliminate or minimize the amount of armor material that would be required to achieve a given level of protection. Figures 15 and 16 show a representative design configuration where structure, noncritical components, and fuel act as natural masking against a large segment of expected small-arms fire aspects. When using this technique, the designer must also consider the accessibility of the elements being masked. The gains in ballistic protection must be weighed against the time and effort required to maintain the aircraft in both peacetime and combat operations to determine the most effective design configuration. The value of various aircraft structures and basic system components can be approximated by using lightweight metallic armor materials as a guide. Reference 10 provides a selection of representative materials for a range of projectile types and sizes. Aircraft-contained fuel is a natural masking element that reduces a projectile's velocity significantly. Refer to classified Volume II (TR-71-41B) for a nomograph developed to evaluate the slowdown of projectiles as they pass through a liquid. Such considerations can minimize any additional masking or armor needed to defeat a specific threat.

3.10.3 ARMOR

Ideally, armor should defeat projectiles or fragments before damage can be inflicted on the component that the armor has been designed to protect. The basic mechanisms for defeat are the projectile breakup and/or absorption of the kinetic energy of impact. All armor and armor systems use these or variations of these methods.

Criteria have been developed to measure the energy absorption and the weight effectiveness of armor material and systems compared to a standard material. These criteria are called merit ratings. They include the protection (V_{50}) ballistic limit (MR_V), and the weight merit rating (MR_W). These merit ratings are in common use, and most armor evaluations are related to them.

Armor materials may be used singly or in combination to form armor systems, or they may be used in the fabrication of the aircraft structure. Material used as part of the aircraft structure is generally referred to as integral armor. Armor material added on, and which does not generally perform a structural function, is referred to as parasitic armor. Armor worn by personnel is categorized as body armor.

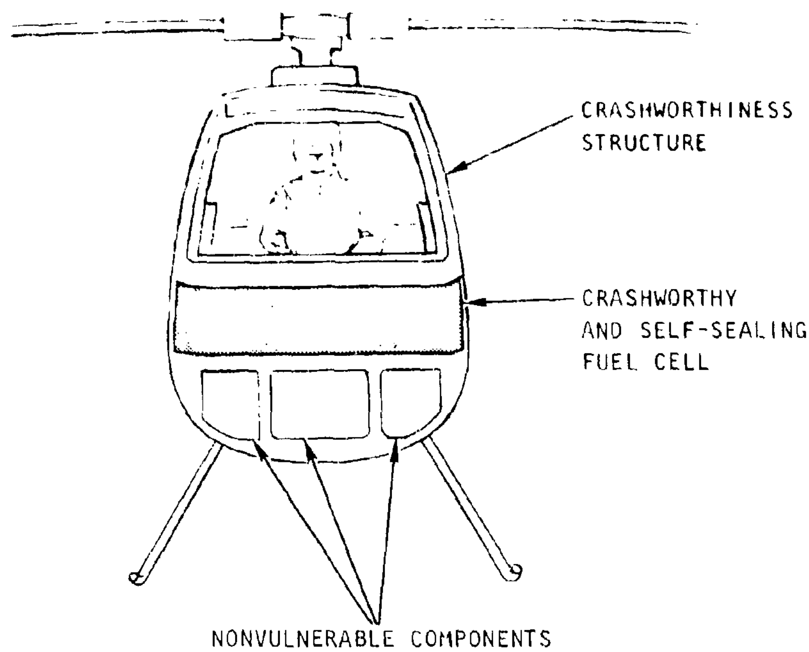


Figure 15. Crashworthiness Structure Masking.

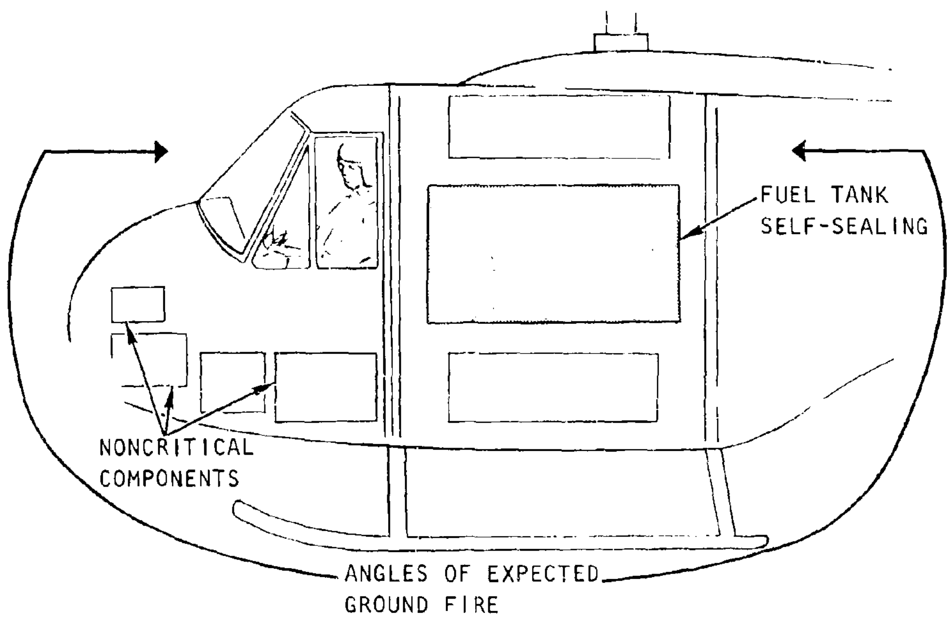


Figure 16. Natural Masking.

Armor systems may be homogeneous or nonhomogeneous. The materials of which they are made may be opaque or transparent; they may be alloys or composites; and they may be machined, cast, laminated, or woven. The fabrication and processing techniques used may determine their resulting armor capability. In addition, how they are used and mounted may enhance their armor capability. Specific uses of the various armor materials are dictated by both their ballistic defeat properties and their nonballistic properties. Thus, there is no general catalog of materials by their use.

3.10.3.1 Definitions: Certain terms are used in contexts oriented to armor materials and systems. Presented here are a number of definitions of common usage.

3.10.3.1.1 Areal Density: The areal density of an armor material is defined as the weight per unit area of a complete armor system expressed in pounds per square foot (psf) of surface area. (The weight value is dependent on material density and thickness.)

3.10.3.1.2 Armor Material: An armor material, as differentiated from an armor system, is a basic material having those properties required to provide a measure of protection against ballistic attack.

3.10.3.1.3 Armor System: An armor system represents some combination of one or more elements made of basic armor material (in some cases supplemented by nonarmor materials) to form an effective ballistic protection device.

3.10.3.1.4 Ballistic Limits: Various definitions of ballistic limits are used to reflect a number of different test conditions and, in the end, a variety of meanings as far as actual protection capability is concerned. In every case, the ability of an armor material to defeat a given threat is defined in terms of the degree of penetration of the armor by the projectile. The definition of what constitutes complete or partial penetration is of critical importance in differentiating between the various types of ballistic limits. Most commonly used in the past have been the Army ballistic limit, Navy ballistic limit, and protection ballistic limit. Of these three, the protection ballistic limit is the one most commonly used and is the type of ballistic limit reflected throughout this report unless otherwise specified. Complete penetration occurs whenever a fragment or fragments from either the impacting projectile or the armor are caused to be ejected from the back of the armor with sufficient remaining energy to pierce a 0.020-inch-thick 2024-T3 aluminum alloy sheet placed parallel to and 6 inches behind the target. Any fair impact which rebounds from the armor plate, remains embedded in the target, or passes through the target,

but with insufficient energy to pierce a 0.020-inch-thick, aluminum witness plate, is termed a partial penetration.

With this criteria, a ballistic limit is defined as a striking element of a kinetic-energy fragment or projectile below which partial penetrations of the armor will predominate. This velocity is generally expressed as protection (V_{50}) ballistic limit, and is a critical velocity at which 50-percent complete penetrations and 50-percent partial penetrations of the armor target can be expected. This concept is shown schematically in Figure 17 along with an illustration of the Army and Navy ballistic limits.

The Army ballistic limit and Navy ballistic limit are discussed briefly herein, primarily for reference purposes. Under the Army ballistic limit criterion, a complete penetration occurs when light is visible through the penetration in the armor or when the nose of the projectile can be seen from the rear of the armor. This criterion for complete penetration is used to approximate the minimum velocity at which a projectile can produce a hole in the armor, yet not necessarily cause any fragments to be displaced to the rear of the plate. The Navy ballistic limit criterion for a complete penetration requires that the projectile or a major portion of the projectile pass through the plate. The Navy criterion for damage evaluation is used mainly for armor-piercing projectiles that contain an explosive filler.

3.10.3.1.5 Composite Armor: Composite armor is an armor system consisting of two or more different armor materials bonded together to form a protective unit.

3.10.3.1.6 Experimental Armor: Experimental armor is an armor material, composite, or configuration for which military specifications have not been established.

3.10.3.1.7 Fair Impact: A fair impact results when an unyawed projectile strikes an unsupported area of a ballistic test sample at an undamaged location which is at least 3 calibers away from a previous impact, hole, crack, edge of sample, or spalled area. Only fair impacts are permitted for rounds used in determining the ballistic limit. (This definition is applicable primarily to steel armor materials.)

3.10.3.1.8 Fragment-Simulating Projectile (FSP): An FSP is a projectile of special shape and size designed for ballistic test firings intended to simulate the effect of typical fragments from high explosive shells, usually of larger caliber than the FSP, on armor samples. Military Specification MIL-P-46593A contains the details on FSP's used in ballistic testing.

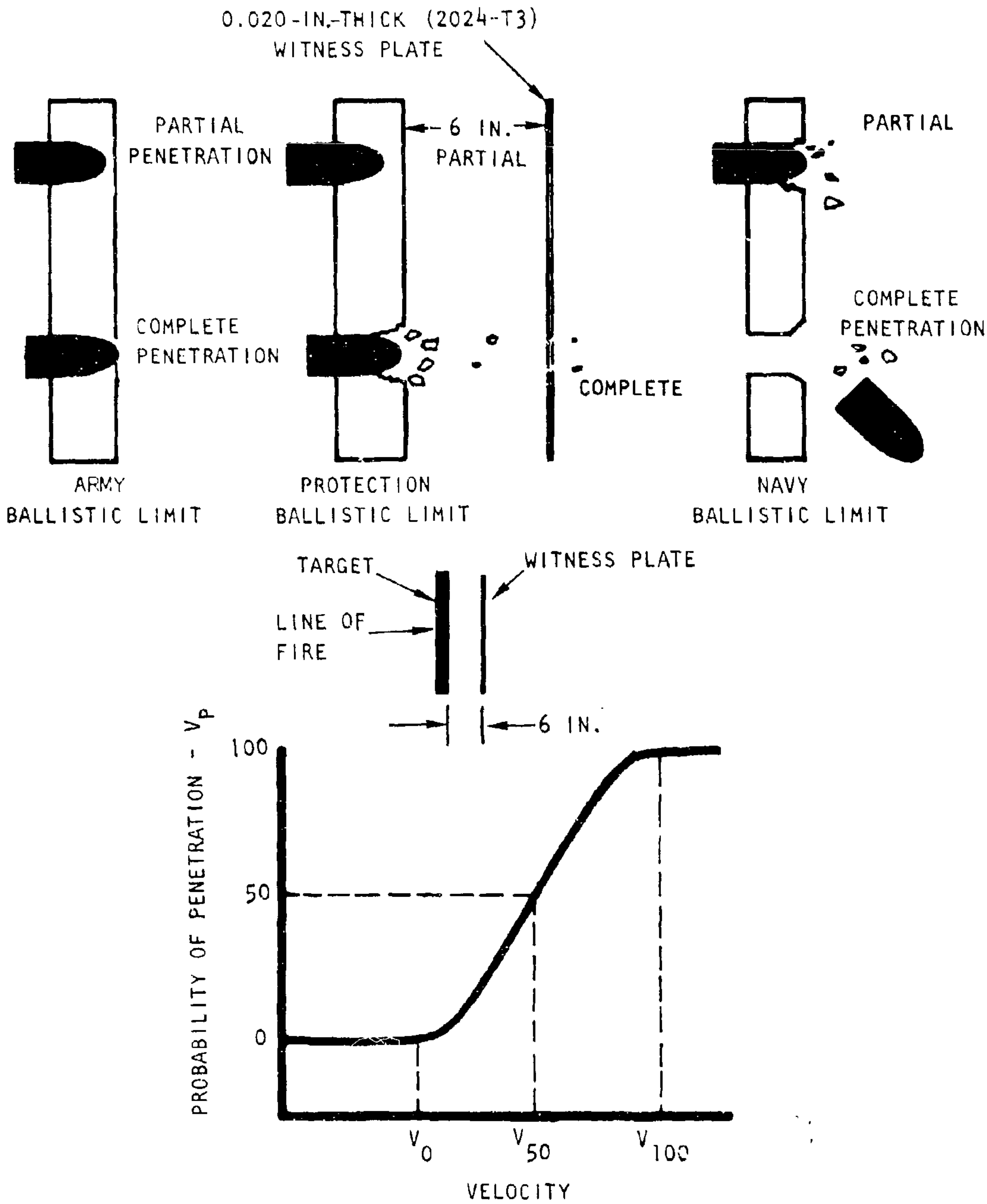


Figure 17. Ballistic Limits.

3.10.3.1.9 Full Multihit Capability: Full multihit capability is the ability of an armor to sustain two or more hits within a distance of 3 calibers without loss in ballistic performance.

3.10.3.1.10 Homogeneous Armor: Homogeneous armor is armor made from a single material that is consistent throughout in terms of chemical composition, physical properties, and degree of hardness.

3.10.3.1.11 Lethality: Lethality is a measure of the destructive effect of a particular projectile on a given target under specified attack conditions.

3.10.3.1.12 Lightweight Armor Material: This is an armor material which will defeat a specific ammunition threat under a specific set of ballistic conditions at an areal density equal to or less than one-half that required by standard homogeneous steel armor.

3.10.3.1.13 Limited Multihit Capability: A limited multihit capability implies lesser degrees of armor protective ability than that provided by an armor having full multihit capability. The armor system suffers damage from an initial projectile impact that will not provide specified protection for a second projectile impact within a distance of 3 calibers distance.

3.10.3.1.14 Maximum Vulnerable Range: This is the range beyond which a specific threat is incapable of defeating a given armor.

3.10.3.1.15 Merit Rating (Velocity): Velocity merit rating (MR_V), used primarily for preliminary screening of armor material candidates for a given application, is the ratio of the V_{50} ballistic limit obtained by test of the candidate armor material to that of the ballistic limit of rolled homogeneous steel armor, MIL-S-12560(ORD), having the same areal density. Velocity merit rating is based on ballistic test at 0 degrees obliquity. In terms of an equation

$$MR_V = \frac{V_{50} \text{ ballistic limit of candidate armor}}{V_{50} \text{ ballistic limit of homogeneous standard steel armor}}$$

NOTE: In the case of an FSP of .30 caliber and smaller, merit rating is measured with respect to Hadfield manganese steel, MIL-S-13259.

3.10.3.1.16 Merit Rating (Weight): Weight merit rating (MR_W) is usually based upon tests at close ranges and 0 degrees obliquity, but it can be based on various obliquities when so specified. The weight merit rating is

used for comparing the ballistic performance of candidate armor materials to the known performance of a standard steel armor (as specified for velocity merit ratings). In terms of an equation,

$$MR_W = \frac{\text{Areal density of standard steel armor}}{\text{Areal density of candidate armor}} \text{ (x 100)}$$

It is calculated for a point where both armors exhibit the same V_{50} protection ballistic limit.

3.10.3.1.17 Minimum Ballistic Limit: The minimum ballistic limit is a value of ballistic limit, wherein the X subscript of the V_X ballistic limit (defined later) falls within an approximate range of 5 to 10. This represents a near-optimum practical value of ballistic limit, with only 5 to 10 percent probability of a complete penetration.

3.10.3.1.18 Obliquity: Obliquity is a measure, normally in degrees, of the extent to which the impact of a projectile on an armor material deviates from the normal to the target. Thus, a projectile fired perpendicular to the armor surface has 0 degrees obliquity.

3.10.3.1.19 Overmatch: Overmatch is a term used primarily in association with steel armor and indicates that the diameter of the impacting projectile is larger than the thickness of the armor plate.

3.10.3.1.20 Partial Penetration: A partial penetration results from any fair impact that is not a complete penetration; more specifically, it is any fair impact that rebounds from the armor plate, remains imbedded in the target, or passes through the target, but with insufficient energy to pierce the 0.020-inch-thick 2024-T3 aluminum alloy witness plate.

3.10.3.1.21 Passive Defense: The passive defense capability of an aircraft is that defense derived from its physical resistance to impact damage and includes basic structural strength, armoring, and certain basic design features incorporating protection.

3.10.3.1.22 Percent Weight Saving: This was the means of measuring armor performance used prior to development of the merit rating concept; the method rated new armor materials by comparison of their areal densities to the areal density of steel armor required to provide equal protection. In equation form:

$$\text{Percent weight saving} = \frac{W_S - W_X}{W_S} \times 100$$

where

W_S = areal density of steel required to provide equal ballistic protection

W_X = areal density of new material

3.10.3.1.23 Petalling: Petalling is the plastic deformation on the face of the armor plate when low-hardness homogeneous armor is struck at low obliquity by armor-piercing projectiles. Metal around the penetration is forced outward in leaflike or petal form.

3.10.3.1.24 Protection (V_{50}) Ballistic Limit: The protection (V_{50}) ballistic limit is a computation made for each test condition on a given armor material by averaging six fair impact velocities comprising the three lowest velocities resulting in complete penetration and the three highest velocities resulting in partial penetration. A maximum spread of 150 fps is used between the lowest and highest velocities used in determining the ballistic limit.

In cases where the spread between the lowest complete and highest partial velocities is greater than 150 fps, the ballistic limit is based on 10 velocities, five of which result in complete penetration and five of which result in partial penetration. In cases where the required number of complete and partial penetrations within 150 fps cannot be obtained, because of insufficient armor sample or other reason, the protection (V_{50}) ballistic limit may be established by a four-round or two-round test program. In the four-round program, the protection (V_{50}) ballistic limit is defined as the average of four fair impact velocities comprising the two lowest velocities resulting in complete penetration and the two highest velocities resulting in partial penetration. A maximum spread of 150 fps shall be allowed between the lowest and highest velocities used in determining ballistic limits. In the two-round program, the ballistic limit is determined from one partial and one complete penetration within 75 fps.

All velocities used in determining the protection (V_{50}) ballistic limit are corrected to striking velocities.

3.10.3.1.25 Punching: Punching occurs when the armor fails in shear and a circular plug about the size of the attacking projectile is pushed from the back side of the plate.

3.10.3.1.26 Solid Armor: Solid armor is all homogeneous and composite armor materials and systems having no air spaces between elements.

where

W_S = areal density of steel required to provide equal ballistic protection

W_X = areal density of new material

3.10.3.1.23 Petalling: Petalling is the plastic deformation on the face of the armor plate when low-hardness homogeneous armor is struck at low obliquity by armor-piercing projectiles. Metal around the penetration is forced outward in leaflike or petal form.

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All velocities used in determining the protection (V_{50}) ballistic limit are corrected to striking velocities.

3.10.3.1.25 Punching: Punching occurs when the armor fails in shear and a circular plug about the size of the attacking projectile is pushed from the back side of the plate.

3.10.3.1.26 Solid Armor: Solid armor is all homogeneous and composite armor materials and systems having no air spaces between elements.

3.10.3.1.27 Spaced Armor: Spaced armor comprises all designs having spaces between armor elements.

3.10.3.1.28 Spalling: Spalling results when a layer of armor in the area surrounding the impact location is detached or delaminated from the armor, especially on the rear face.

3.10.3.1.29 Striking Velocity: Striking velocity is the relative velocity between the target and the projectile at the instant of impact. It is normally expressed in feet per second (fps) and is determined from projectile initial (muzzle) velocity, range considerations, and aircraft velocity.

3.10.3.1.30 Threat: Threat is an expression of possible attack conditions to be imposed upon an aircraft and is measured in terms of projectile size and type, impact velocity, and obliquity.

3.10.3.1.31 Undermatch: Undermatch, a term used primarily in association with steel armor, indicates a relationship in which the diameter of the impacting projectile is less than the thickness of the armor plate.

3.10.3.1.32 Unyawed Projectile: A projectile is considered to be unyawed when it strikes the armor test panel at an attitude such that its geometrical axis is within 5 degrees of its trajectory path.

3.10.3.1.33 V_{50} Ballistic Limit: In general, this is a velocity at which the probability of penetration of an armor material is 50 percent.

3.10.3.1.34 V_X Ballistic Limit: This is any expression of ballistic limit (including V_{50}) wherein the X subscript denotes probability of complete penetration. For example, a V_{05} ballistic limit would be one at which the probability of complete penetration would be 5 percent.

3.10.4 ARMOR EFFECTIVENESS CRITERIA

3.10.4.1 Introduction: Prior to the determination of criteria for armor effectiveness, the projectile threat mechanisms as well as those mechanism of the armor that defeat the threat must be known.

3.10.4.2 Threat and Defeat Mechanisms

3.10.4.2.1 Armor Defeat: Defeat of an armor material is normally defined in terms of the degree of penetration of the armor by a specific projectile. While this degree of penetration may be defined in varying ways, the basic question still involves consideration of what happens to the

armor material under impact by the projectile. In the most basic terms, any one of three possible results may occur: the projectile may perforate the armor, the projectile may become partially imbedded in the armor, or the projectile may be deflected by the armor with little or no penetration occurring. In addition to these three basic penetration possibilities, various secondary or side effects can occur in specific situations. Included among these effects are punching, petalling, spalling, bulging, and cracking. With the exception of bulging and cracking, which are self-explanatory, these terms are defined in paragraph 3.10.3.1.

Of primary concern in the case of side effects is the possibility that secondary fragments, possibly of a lethal nature, might be created in the process. Such secondary fragments, in some cases, would possess a damage potential greater than that of the original projectile because they would affect a greater area. A second result of these side effects might be a serious degradation of any capability of the material to sustain a second hit in the same general area.

3.10.4.2.2 Threat Defeat: For information on defeat of small-arms projectiles, refer to Volume II (TR-71-41B).

The protection ballistic limit is a very meaningful measure of protection, particularly in ground warfare, because it defines the limiting velocity at which damage occurs beyond the armor, this damage being lethal to personnel. It can be determined quite readily by range personnel with a minimum of ambiguity. The Army ballistic limit, by contrast, does not include the energy absorbed in the final stage of penetrating the back surface of the armor. This energy may be a significant part of the total energy absorbed, or it may be very little depending upon the armor hardness, the test conditions, or the type of exit condition (spalling, punching, etc). In general, the protection ballistic limit is very close to the Navy ballistic limit at low obliquities of attack, whereas the three types of limits may be essentially the same at high obliquities or when the projectile markedly overmatches the armor (projectile diameter is much greater than the plate thickness).

In actual testing, a number of variables must be controlled or corrected for in order to obtain accurate ballistic limits. Velocity measuring equipment must be calibrated and its reliability assessed. The measured velocity must be corrected to striking velocity. It is necessary to determine and then use correction factors for the thickness and obliquity variations.

In all terminal ballistic tests, it is important to use armor materials and ammunition of known metallurgical and mechanical properties and

history. In addition, information on the behavior of the armor and ammunition should be reported by the testing organization. This type of information is extremely valuable in assessing the reliability of the data and in providing comparisons with similar ballistic data. The presence of spalling, punching, and cracking may indicate deficiencies in the quality of the armor. Projectile breakup may be caused by the quality of the projectile, or an ability of the armor that causes the projectile to shatter.

Generally speaking, ballistic limits, merit ratings, and weight saving percentage values mean very little to a field commander. He needs to know the range within which the vehicle or aircraft is vulnerable to specific types of hostile weapons. To provide him with this information, the level of protection afforded by an armor system must be evaluated for expected combat encounter conditions.

3.10.5 ARMOR MATERIALS

Classification of armor by major material types is as follows:

- Metallic
- Nonmetallic transparent
- Nonmetallic opaque
- Composite

General information is presented in the following paragraphs to acquaint the reader with the overall spectrum of armor material types. More detailed information on specific armor system capabilities are contained in Appendix II of this document.

3.10.5.1 Metallic Armor: Metallic armors exist as specification armor, experimental armor, and spaced armor systems.

Metals used in armor applications include steel, aluminum, titanium, magnesium, lithium, and beryllium. Magnesium, lithium, and beryllium are not available as specification armors.

3.10.5.1.1 Steel: Steel types used for armor include rolled, wrought, case hardened, and dual hardness. Advantages in the use of steel include cost, availability, fabricability, and load-carrying ability.

Disadvantages include weight and lack of corrosion resistance. Steels classified as specification armor include:

Wrought homogeneous steel	MIL-S-12560B(ORD)
Nonmagnetic rolled steel	MIL-A-13259A(ORD)
Wrought high-hardness steel	MIL-S-46100(MR)
Face-hardened steel	JAN-A-784
Roll-bonded dual-hardness steel	MIL-S-46099(MR)

3.10.5.1.2 Aluminum: Armor materials include cast and wrought aluminum alloy. Nonballistic advantages include weight, fabricability, availability, and corrosion resistance.

Aluminum specification armor includes:

Weldable aluminum alloy	MIL-A-46027(MR)
Heat-treatable, weldable aluminum alloy	MIL-A-46063B(MR)

3.10.5.1.3 Titanium: Typical titanium specifications for armor include:

Weldable titanium alloy	MIL-T-46077(MR)
Titanium alloy	MIL-A-23556

The advantages in using titanium are typical of all light metals.

3.10.5.1.4 Magnesium, Lithium, and Beryllium: Magnesium, lithium alloys, and beryllium armor have no specifications and are considered as experimental.

3.10.5.2 <u>Nonmetallic Transparent Armor</u>: Specifications for armor glass are:

- Glass and composite glass

Bullet-resistant flat-laminated glass	MIL-G-5485
Laminated glass-faced composite	MIL-A-46108 (MR)

- Acrylic

Plexiglas (commercial)	MIL-P-5425

• Polycarbonate

Lexan (commercial) (General Electric trade name)	None

3.10.5.3 Nonmetallic Opaque Armor: Nonmetallic opaque materials may be used as elements in composite armor. Included in these materials are aluminum oxide, boron carbide, nylon, boron, and fiber glass. Bonded and unbonded ballistic nylon may be used alone against certain shell fragments.

3.10.5.4 Composite Armor: Most composite armor falls into the experimental category. Categories of composites include metal-metal, metal-ceramic, metal-organic, metal-organic-ceramic, and ceramic-organic. The specification for composite material is MIL-A-46103(MR).

The comparison of thickness and areal density of various armor materials is shown in Figure 18.

Further description of composite armor will be found in Appendix II.

3.10.6 ARMOR SELECTION

To determine armor material needs, the designer must have the following information:

a. Aircraft affected

(1) Type

(2) Model

(3) Serial number(s)

b. Protection to be provided for

(1) Crewmembers

(a) Pilot

(b) Copilot

(c) Other

(2) Aircraft component(s)

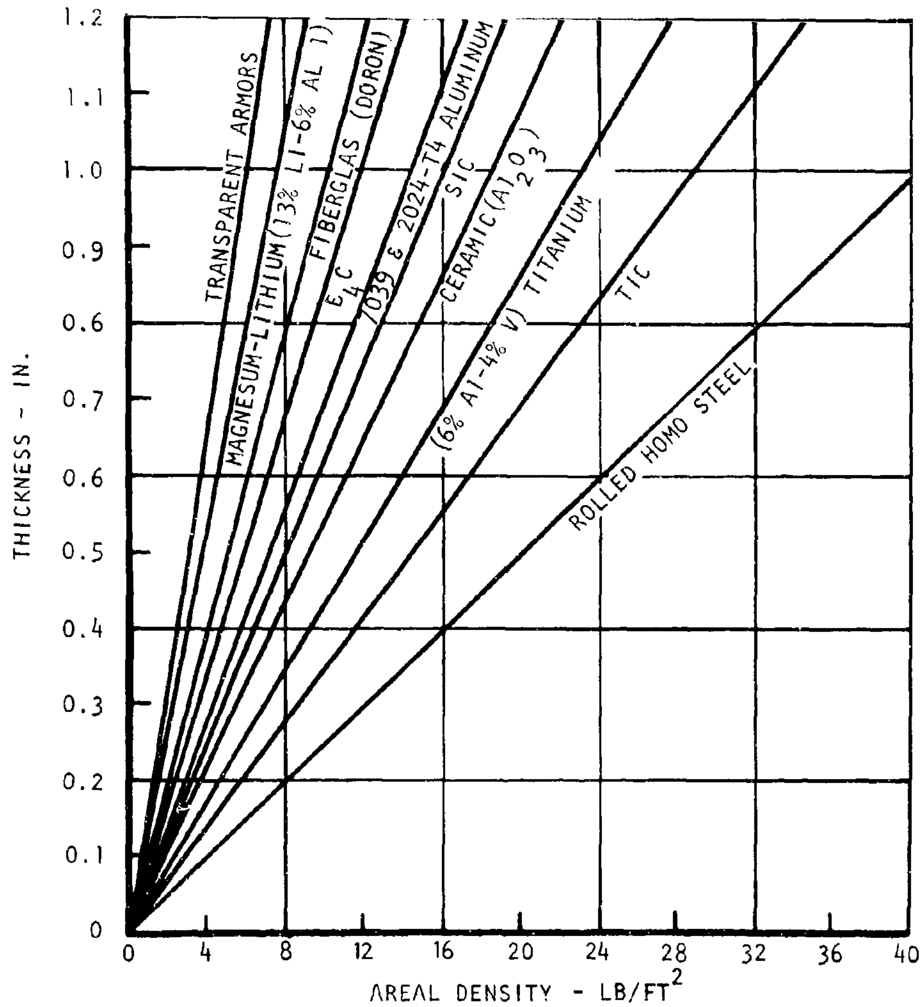


Figure 18. Conversion Between Areal Density and Thickness for Candidate Armor Materials.

c. Nature of required installation

(1) Permanently installed

(a) Factory

(b) Field (kit form)

(2) Removable

(3) Structural capabilities required

(4) Nonstructural

d. Aircraft status:

(1) New design

(2) Undergoing major modification

(3) Operational (in service)

e. Extent of protection

(1) Direction(s) (from rear, bottom, etc)

(2) Angle(s)

f. Threat to be defeated

(1) Projectile type and size (e.g., caliber .50 AP M2)

(2) Impact velocity

(3) Impact obliquity (worst condition)

(4) Single or multiple impact capability

g. Design limitations

(1) Allowable armor weight

(2) Allowable effect on aircraft balance

(3) Allowable restrictions (if any) on aircraft operation or performance

h. Logistic considerations

(1) Cost limitations

(2) Delivery schedule requirements

i. Special considerations (if/as applicable)

Those efforts necessary for correct armor selection include the following:

a. Threat analysis.

b. An assessment of the protection level of the existing indigenous protection (existing aircraft structure and components) around the item to be protected for the directions of interest.

c. Design limitation review.

d. Determination of armor material/systems compatible with design limitations.

e. Determination of ballistic and applicable nonballistic characteristics of the candidate materials/systems. This includes determination of multihit, spall, and fragment prevention or protection required by armor use.

f. Selection of the candidate armor materials/systems that minimize overall aircraft/crew performance degradation, and determination of the cost impact of the candidates. The choice is generally based on producibility, maintainability, and cost and performance/cost trade-offs, after an armor configuration has been established.

g. Consideration of aircraft balance, armor application, fabrication, and installation factors.

3.10.7 ARMOR INSTALLATION/FABRICATION

Improper installation of armor can degrade its effectiveness. Design in consonance with the guidelines listed herein is suggested. Where time limitations are specified by the procuring activity, due regard must be given to maximum allowable times for armor installation or removal.

Airframe manufacturing tolerances should be taken into consideration to facilitate interchangeability of parasitic armor kits between individual aircraft.[12-14]

3.10.7.1 Design of Armor Elements: In the design of satisfactory armor elements, due consideration must be given to a number of typical factors in addition to the weight limitations. The nature of these factors varies with the type of armor involved. Some of the more important of these factors as they relate to ceramic-plastic armor and to metallic armor are as follows:

a. Ceramic-plastic armor

(1) Armor panels should be designed, if possible, so that the overall dimensions will be a multiple of individual standard tile dimensions to minimize ceramic tile cutting, thereby reducing fabrication costs.

NOTE It may be desirable to consider use of a monolithic facing in lieu of individual tiles where the ceramic element of the armor panel (curved or flat) can be produced within the current state-of-the-art. Such a procedure would provide definite advantages in ballistic protection capability, because the ballistic protection provided at or near tile joints normally is only about 85 percent of that provided at the center of the tile.

(2) Flat panels should be used wherever possible. Curvatures can be accommodated by use of monolithic panels as previously mentioned, or by faceting a series of flats.

(3) Individual elements must be designed with due regard to attachment and installation methods to be used.

NOTE Through-bolting should be avoided wherever possible.

(4) Dynamic deformation (backing bulge) at impact should be accommodated by allowing a clearance between the backing surface and aircraft structure or equipment. This space allowance should be a minimum of 1.00 inch for .30 caliber armor and 1.50 inches for .50 caliber armor.

(5) A spall shield material should be incorporated on the tile surface to contain the ceramic at impact.

(6) In any case where there is a possibility of error, the design should provide a positive means for insuring that armor is installed in proper orientation.

(7) A minimum of four support points should be used to attach each piece of armor.

b. Metallic armor

(1) The size of armor panels should be consistent with weight limitations for any single piece of armor, and it should be a function of location. In areas where installation or removal would be hampered by the existing structure and/or equipment, the weight should be reduced to a minimum.

(2) Shielding of the forward spall should be accommodated by incorporation of spall deflection plates or nonmetallic spall shields, where applicable.

(3) In the case of dual-hardness or face-hardened steels, the design should provide a positive means of insuring that the armor is installed with the hard face outward (i.e., toward the impacting projectile).

(4) Allowances for dynamic deformation should be considered (similar to the ceramic-plastic armor).

(5) The design procedures used must consider the fabrication capability of the armor used. Table V presents fabrication data for three metallic armors.

3.10.7.2 <u>Armor Attachment Methods</u>: Satisfactory attachment design will require consideration of the type of armor materials involved, features of the aircraft mounting/backup structure to be used, and nature of the planned attaching bracketry. Typical attachment methods for ceramic-plastic armors and for metallic armors differ as outlined herein. These attachment methods for the two armor types are illustrated in Figures 19 and 20, respectively.

In general, attachment methods recommended for use with ceramic-plastic armor include the following:

a. Threaded inserts

b. Bolt-through extended backing material

TABLE V. FABRICATION DATA FOR METALLIC ARMOR MATERIALS

Parameter	High-Hardness Steel	Dual-Hardness Heat-Treated Steel	Dual-Hardness Ausformed Steel
Maximum Plate Size	0.250 in. thick, 33.5 x 72 in. 1.250 in. thick, 72 x 56 in.	66 x 96 in.	26 x 96 in., up to 2,000 lb
Minimum Radius of Curvature (for Typical Small-Arms Threat)	10 times thickness.	Approximately two times thickness in annealed condition.	3 x 9 in., depending on thickness.
Extent of Compound Curvature	7 in., deep dishes have been explosively formed.	Very small radius in both directions in annealed condition.	Unknown.
Ballistic Effects of Curvature	None.	Slight improvement.	None.
Tools Required for Cutting	Torch cutting	Gas or plasma arc techniques.	Gas or plasma arc techniques.
Welding Procedures Required	Austenitic stainless steel electrodes by MIG* or submerged arc techniques; or with low hydrogen ferritic electrodes	<u>Annealed condition</u>: Hardex heat-treatable electrode gives ballistic joint. <u>Heat-Treated Condition</u>: Stainless steel electrode with 700° F preheat	MIG* methods.
Drilling	Possible, but requires carbide tips. Spot-heating with torch before drilling may lessen difficulties.	Possible, with special carbide tool if heat-treated.	Possible, with masonry-type bits.
Recommendations for Attachment to Structure	Through-bolting.	Through-bolting.	Through-bolting.
Bolt Tension in Through-Bolting	Not important.	Not important.	Not important.
Panel Joining Methods	Welding or mechanical joints.	Welding or mechanical joints.	Welding or mechanical joints.
Ballistic Joints Between Panels	Cannot be achieved by welding unless material thickness is increased in heat-affected zone.	Can be achieved by welding with Hardex electrode in annealed condition.	Cannot be achieved by welding unless material thickness is increased in heat-affected zone.

*MIG - Metallic inert gas

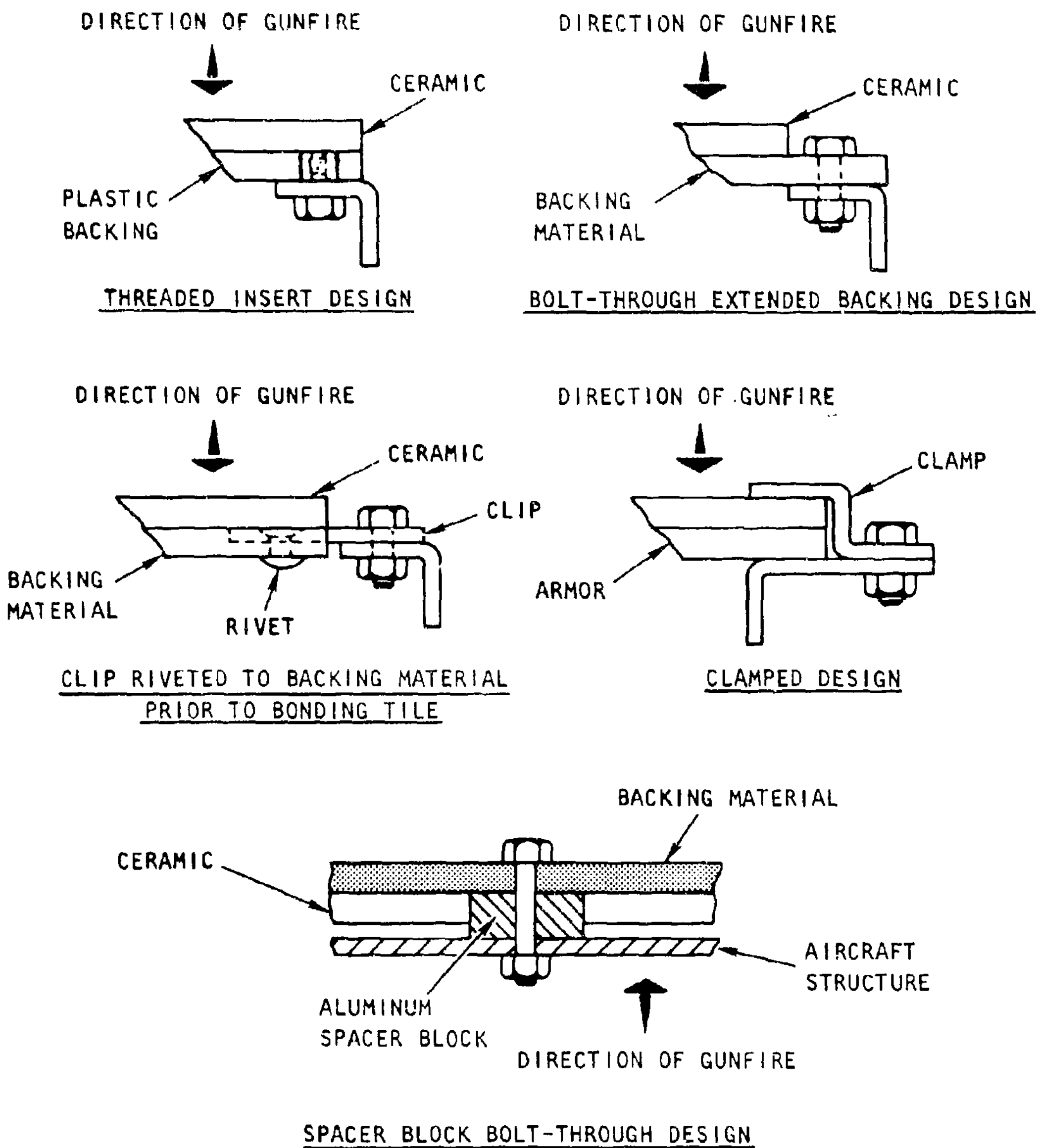


Figure 19. Ceramic-Plastic Armor Attachment Methods.

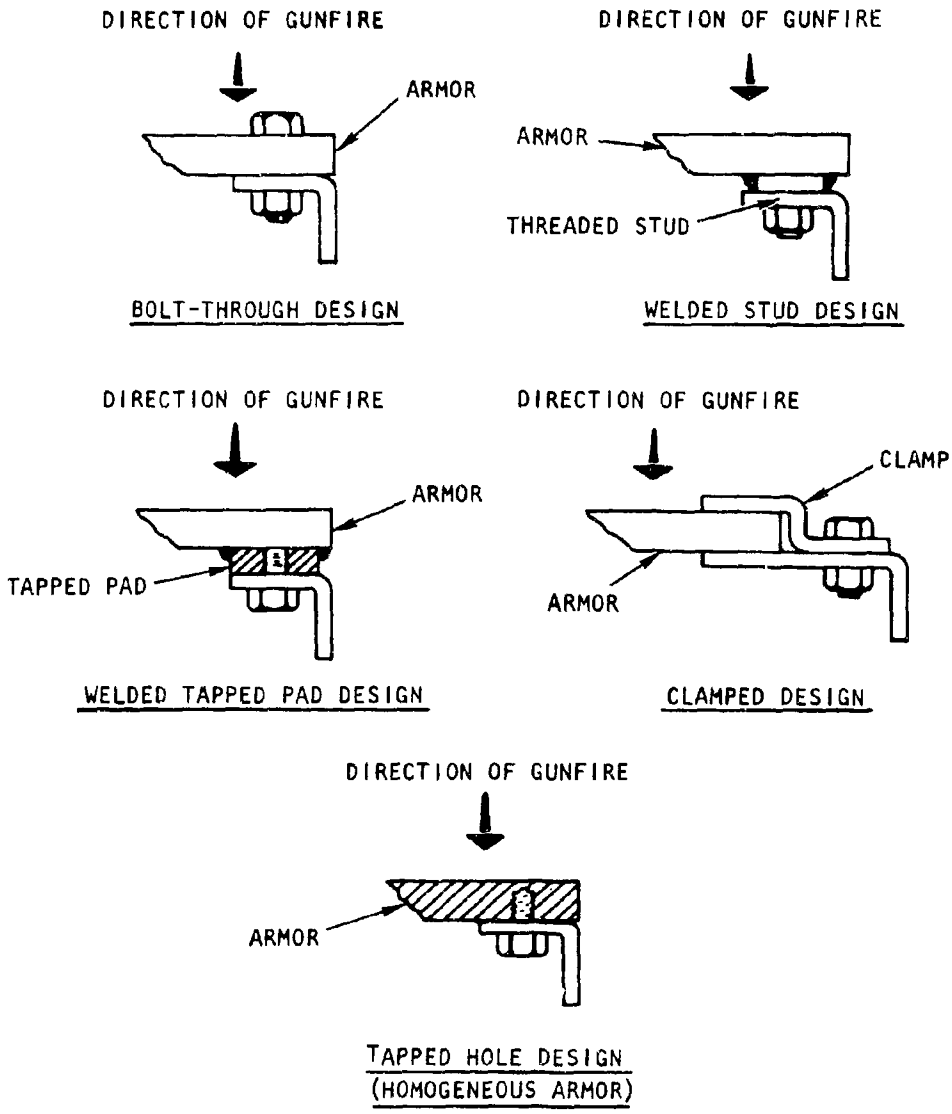


Figure 20. Metallic Armor Attachment Methods.

c. Riveted bracketry attached to backing material prior to bonding of tile

d. Clamping

e. Bonded stud or nut

Recommended attachment methods for metallic armor include:

a. Bolt-through design

b. Tapped holes

c. Threaded inserts

d. Welding

e. Clamping

3.10.7.2.1 Bracketry Design: Bracketry for attachment of armor panels must be designed to meet specific flight and ballistic (dynamic) loading conditions. Crash loading must also be considered where applicable. Bracket design normally is based upon the most critical of these three conditions for the specific case at hand. The following basic considerations apply:

a. When designing to flight loads, the bracketry should neither yield below the limit load nor fail below the ultimate load.

b. When designing to crash loads, the bracketry should not fail below the crash load. Yield is of no consequence, provided it does not endanger personnel or interfere with emergency escape.

c. When designing to projectile impact loads:

(1) Bracketry may yield but must not fail under limit load

(2) Standoff distance of bracketry should be such that no deflection or deformation of the armor or of bracketry will cause interference with any critical system function.

(3) Bracketry must be sufficiently strong after being subjected to the limit load to withstand flight loads without deforming to the point of interference with critical systems. It is not necessary to design for crash loads after projectile impact, provided there is no danger to personnel.

Although stress analysis based upon the foregoing requirements will be mandatory to verify the end design, certain approximations based on past experience can be used for purposes of preliminary evaluation. In general, experience has shown that brackets of 0.090-inch-thick 2024-T3 aluminum are commonly used in armor systems designed for protection against a .30 caliber threat. Similarly, 2024-T3 aluminum brackets of 0.125-inch thickness would be a good starting point in the design of .50 caliber armor installations.

3.10.7.2.2 Backup Structure Considerations: A final factor to be considered in the design of an armor installation involves analysis of the requirements to be imposed upon backup structure to provide sufficient structural hard points for armor mounting. In new aircraft, the structure should be designed to support the required armor, whether it is to be built in initially or added later. In existing aircraft, structural modifications should be planned according to the following criteria:

a. When armor is added to a system in some way other than directly to the structure, the structural integrity must be maintained in accordance with original design conditions of flight loading, crash loading, or projectile impact loading.

b. When armor is tied in directly to the backup structure, this structure should not:

   (1) Yield under limit load or fail under ultimate load for the flight load condition.

   (2) Fail under ultimate load for the crash load condition.

c. When designing for projectile impact loads, existing backup structure must be strengthened if necessary so that it will not yield under the projectile impact load. Structural reinforcement will be required under the following conditions (NOTE Impact load refers here to the energy of the projectile specifically defined as the threat as it will affect the structure upon impact.):

   (1) If deformation of the existing armor backup structure after a projectile impact would cause interference with the system being protected.

   (2) If failure of the existing armor backup structure after a projectile impact would cause the armor to come loose and/or cause system interference.

(3) If failure of existing primary airframe load-carrying structure that also serves as armor backup structure would occur after a projectile impact.

(4) If the existing airframe primary structure that also serves as armor backup structure would yield after a projectile impact to the extent that the structure could not carry its design ultimate load.

d. A structural reinforcement may be required under the following conditions:

(1) If the secondary airframe structure that also serves as armor backup would yield after a projectile impact, but without system interference.

(2) If failure of existing secondary airframe structure that also serves as armor backup structure would occur after a projectile impact, but without the armor coming loose and/or without system interference.

(3) If the existing primary airframe structure that also serves as armor backup structure would yield after a projectile impact, but to such a minor extent that the structure would still be capable of carrying the design ultimate load.

e. In those cases in which a structural reinforcement is not required, the advantages and disadvantages of a reinforcement at the time of armor installation should be considered. The following general points apply:

(1) If field level maintenance cannot be accomplished on the backup structure, the reinforcement should be made.

(2) If repair to the damaged backup structure after a projectile impact is estimated to be more extensive than the reinforcement prior to a projectile impact, the reinforcement should be made.

(3) If the required reinforcement is extensive, but structural repair procedures are are also extensive, and if it can be determined that spares are available, spares should be used in lieu of structural modification.

Typical armor installations are presented in Figures 21 through 25 that illustrate a few of the armor protection modifications that have been made on U.S. Army aircraft.

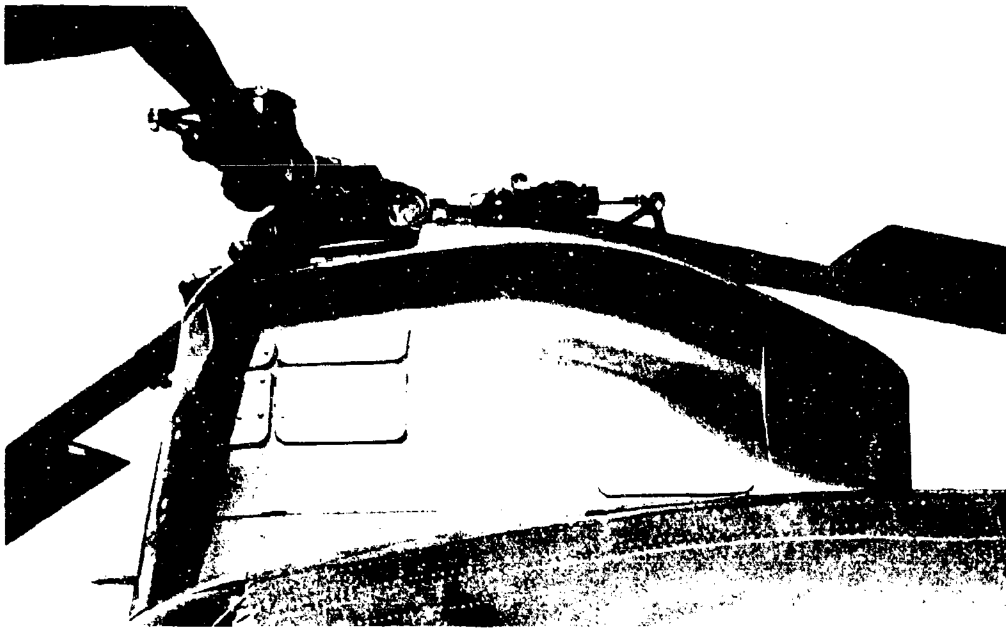


Figure 21. Parasitic Armor Covering Vital Areas of a Helicopter Transmission.

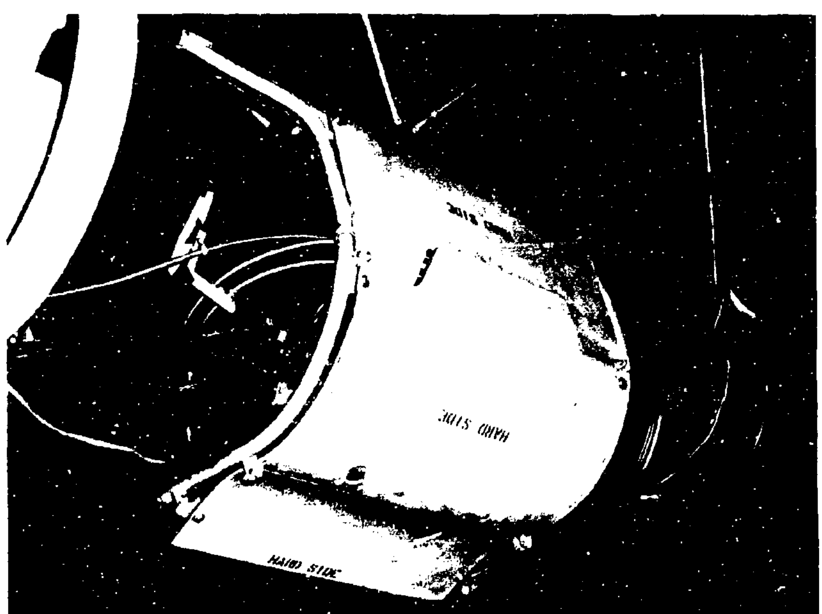


Figure 22. Engine Accessory Section Armor.

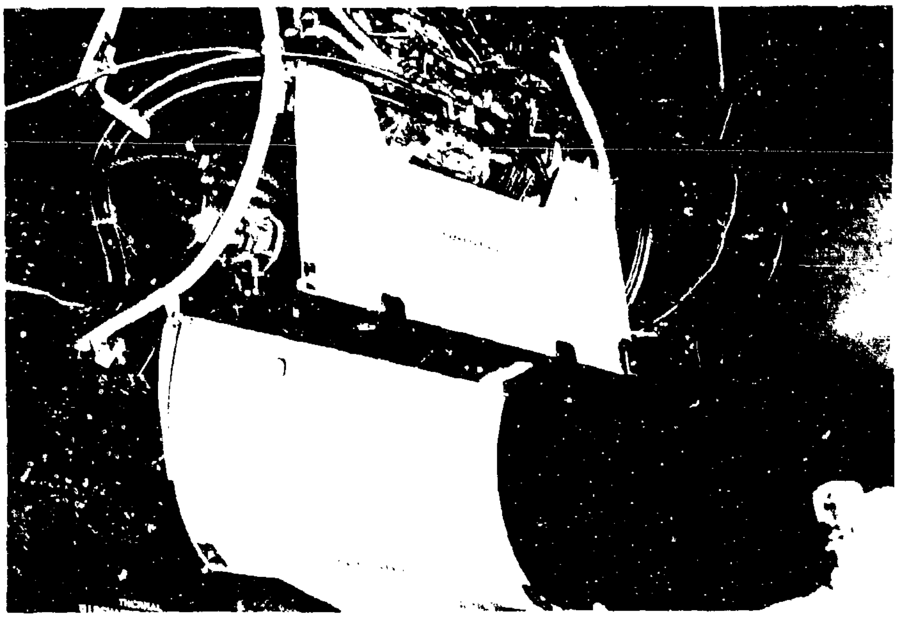


Figure 23. Engine Accessory Section Armor Open for Access.

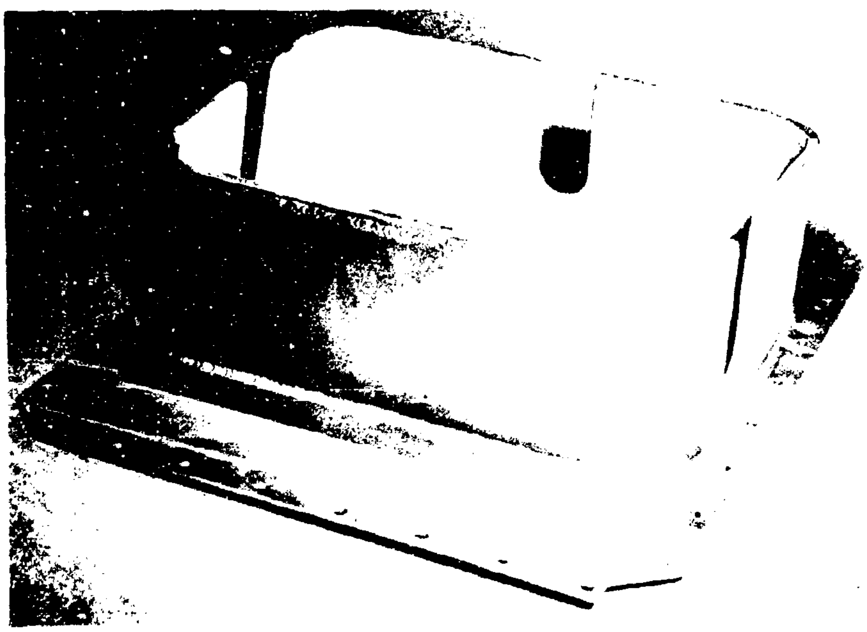


Figure 24. Engine Oil Sump Armor.

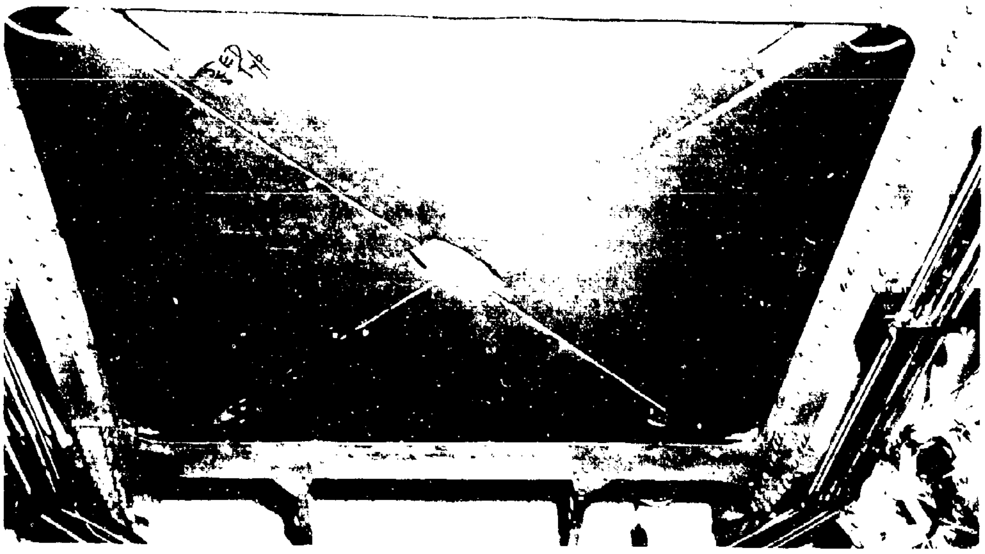


Figure 25. Parasitic Armor - Sectioned to Facilitate Installation and Removal.

CHAPTER 4

SPECIFIC DESIGN PROTECTION TECHNIQUES

4.1 INTRODUCTION

The incorporation of ballistic protection features in an aircraft, whether in its initial design or as a modification, requires consideration of specific survivability enhancement techniques for the overall configuration and for each of the individual aircraft subsystems. Specific information and guidance in these areas are presented in this chapter as a collection of methods that can be used as candidate survivability features for consideration in individual aircraft design programs. Each technique, or combination of techniques, must be selected on the basis of producing the most effective overall aircraft system. The impact and interrelationships of survivability features on performance, safety, maintenance, reliability, and other pertinent operational factors must be evaluated. It is the responsibility of design management to conduct such evaluations. Basic information on trade-off factor considerations are contained in Chapter 5. The ballistic protection of each aircraft design must be integrated as a total system and not as independent and unrelated efforts in each subsystem.

4.2 GENERAL CONFIGURATIONS

4.2.1 INTRODUCTION

The initial design effort for a new aircraft configuration is where the most beneficial survivability design features can be incorporated for the least penalties. To accomplish this, considerations for survivability must be part of the design integration process along with the balance of performance and design specialties requirements. The configuration designer must have sufficient information on the characteristics of each type of hostile weapon system to which the aircraft may be exposed. At the same time, he must have information on all of the current design techniques that may be used to minimize vulnerability or otherwise optimize survivability. This section contains information on general survivability enhancement methods that can be used for protection against enemy small-arms weapons. Their use is dependent upon the designer's ingenuity to integrate them with the other design requirements and constraints of his particular design.

4.2.2 PRIMARY DESIGN CONSIDERATIONS

4.2.2.1 <u>Mission/Threat Factors</u>: The operational mission requirements of U.S. Army rotary-wing and fixed-wing aircraft provide information upon the most probable encounter conditions with enemy weapons. These include the flight conditions, amount of exposure, and most probable directions of small-arms fire. The size, type, and intensity of enemy weapons are variables that greatly affect the survivability of the aircraft and its personnel. These factors must be carefully considered during the initial design effort to insure that a small change in the postulated threat or operational use of the aircraft will not immediately decrease its probable survivability to an unacceptable level. Consider, therefore, the capabilities of each of the candidate survivability design features against the full range of enemy weapons and mission parameters.

4.2.2.2 <u>Configuration Arrangements</u>: The placement and arrangement of aircraft structure and subsystems can be used to increase survivability against enemy small-arms fire for modest or no system penalties. The basic methods, which are described in the following paragraphs, are:

- Redundancy/separation
- Masking/armor
- Concentration/shielding of vulnerable elements
- Hazardous material placement/containment
- Minimized detection

4.2.2.2.1 Redundancy/Separation: Many of the major subsystems of an aircraft cannot be designed to be completely protected against the total range of enemy small-arms weapon effects with existing technology.

In these cases, duplication of the subsystem function is a method of achieving a practical, higher degree of survivability. In most cases, duplication is also made for reasons of aircraft safety and reliability and provides the basis for integrating the requirements with each of these design specialties at the same time. Where redundancy is used for safety and reliability reasons to prevent injury, aircraft damage, and mission failures, separation and mutual masking of the redundant systems must also be considered for survivability against small-arms weapon effects. Figure 26 illustrates the basic concept for redundancy, separation, and mutual masking of rotary-wing aircraft engines. The two engines are located on opposite sides of the fuselage with structure and equipment

between them. This provides a natural barrier that minimizes the probability of single- or multiple-projectile hits from one direction. Figure 27 shows a similar separation and mutual masking of a fixed-wing aircraft.

This basic technique should be considered for each of the flight or mission-essential subsystems. These include flight controls, engine fuel feed and supply, crewmembers, electrical power, and hydraulics.

Figure 28 shows an example of tandem seating of pilot and copilot for rotary- or fixed-wing aircraft. Armor material on the back of the pilot's seat serves two purposes. It protects the pilot from ballistic projectiles from the rear quarters and also provides frontal protection to the copilot.

Figure 29 shows an example of side-by-side seating. Separation between pilots is limited for small aircraft. Structural masking or armor between the seats can provide protection that will reduce the chances of simultaneous injury of pilot and copilot from small-arms fire from the side.

4.2.2.2.2. Masking/Armor: Ballistic defeat of small-arms projectiles is a design technique that has been used for aircraft since World War I. In that conflict, pilots purloined iron stove lids from the kitchen and placed them on the cockpit seats to obtain a degree of protection, or psychological comfort, against ballistic threats. An enormous amount of development and testing has been conducted to produce better and more efficient lightweight armor materials that can be used for aircraft. At the same time, aircraft performance and construction methods have improved at a tremendous rate so that the structures and the contained equipment themselves can provide a significant degree of ballistic protection if located properly in relationship to vulnerable elements. Such protection is referred to as natural "masking." Effective use of this and other techniques such as redundancy, separation, etc., can minimize or eliminate the need for the amount of parasitic armor that would otherwise be necessary to provide a given level of protection. The initial design of an aircraft should be conducted with this in mind, along with the other design considerations and requirements. The predominate directions of expected hostile small-arms fire are an important factor in this effort. The main emphasis of masking, plus the other techniques, with no or minimal armor protection should be directed toward these directions of fire. Figure 30 shows a representative arrangement where natural masking can be used in conjunction with parasitic and integral armor to provide an effective protective configuration. The combinations and variations of such techniques will be dependent upon the specific design requirements, levels of hostile threat, and ingenuity of the designer. Basic data on armor materials and installation considerations are contained in Chapter 3.

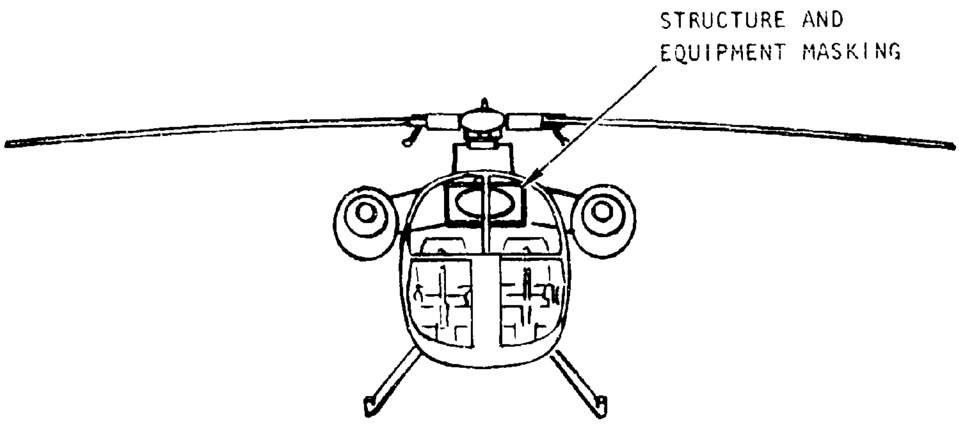


Figure 26. Engine Redundancy/Separation and Masking on Rotary-Wing Aircraft.

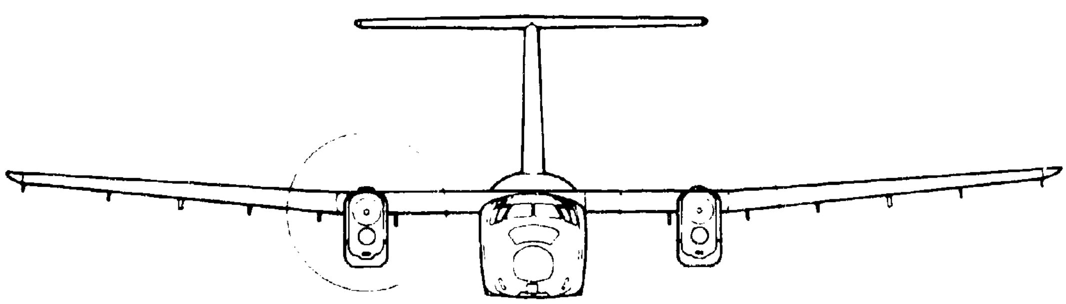


Figure 27. Separated and Masked Engines on Fixed-Wing Aircraft.

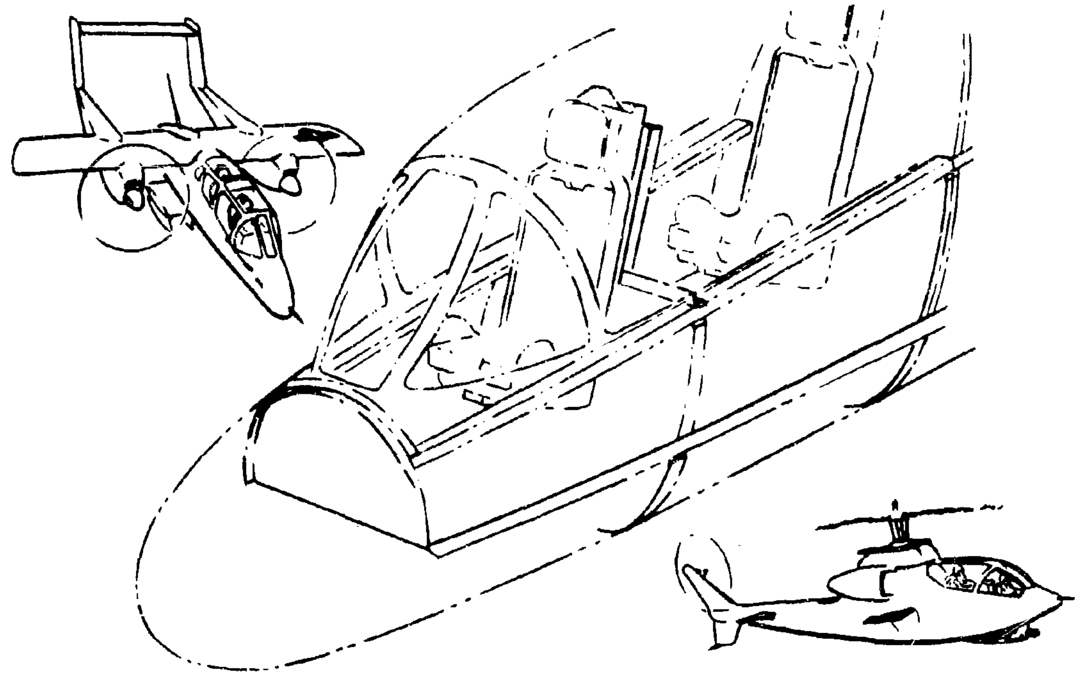


Figure 28. Redundant Pilot Tandem Seating Arrangement.

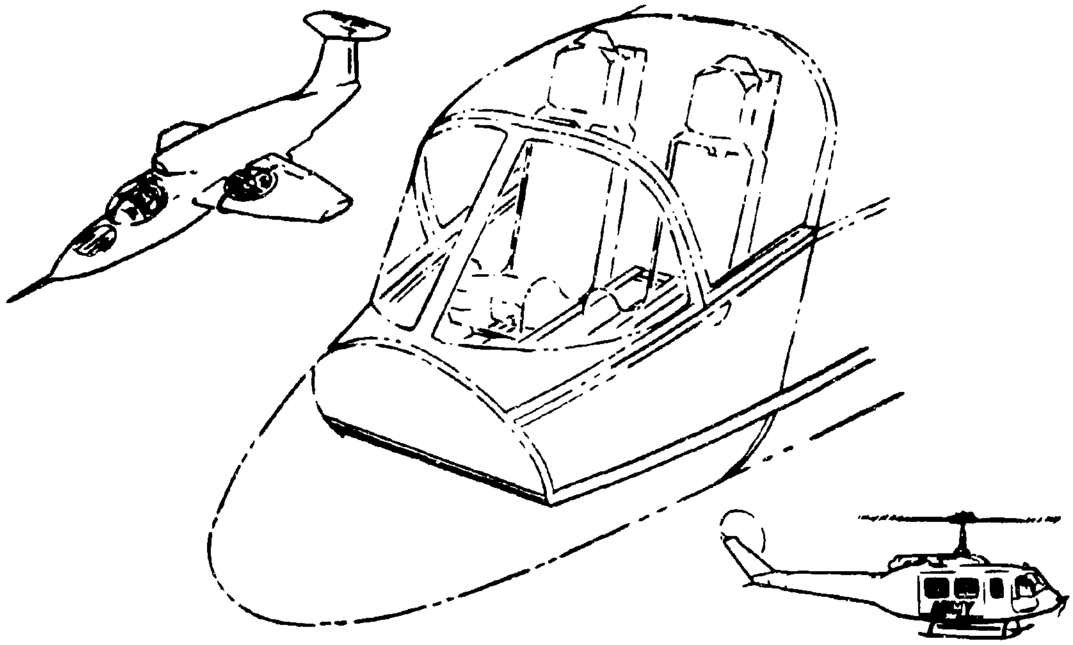


Figure 29. Redundant Pilot Side-by-Side Seating Arrangement.

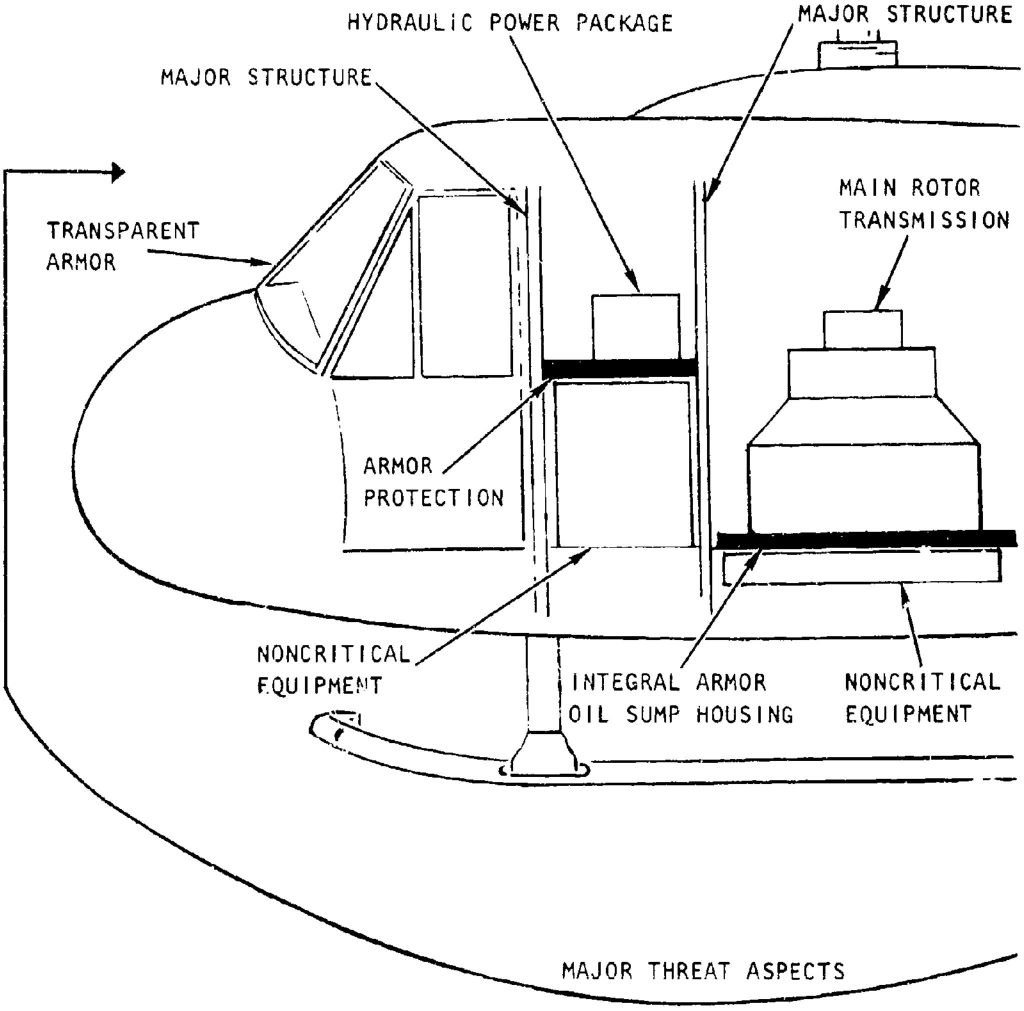


Figure 30. Masking and Armor Protection.

4.2.2.2.3 Concentration/Shielding of Vulnerable Elements: In many design areas, there are types of equipment that do not lend themselves to being designed to withstand ballistic threats. Control valves, filters, pressure transducers, and gages are examples of such elements whose integrity may be vital to continued flight or mission completion. Consideration should be given to miniaturization and concentration of such subsystems within the aircraft configuration to minimize their exposure to ballistic threats and the amount of masking or armor that would be required to protect them. Figure 31 shows an example of an integrated hydraulic system package that incorporates the reservoir, pump, filter, and control valve. The amount of armor or masking is thereby minimized and, for the protection required, imposes a lower weight and cost penalty than a conventional installation where the system is "spread out" through the airframe and thus has interconnecting lines that are quite vulnerable and add to the problem.

4.2.2.2.4 Hazardous Material Placement/Containment: Consideration should be given to the placement of hazardous materials (such as fuel, munitions, hydraulic fluid, lubrication oil, oxygen systems, and batteries) within the design configuration and to their response to small-arms weapon fire. The consequences of their response or liberation upon the vulnerability of personnel and/or flight/mission-essential elements should be examined. Fire and/or explosion potentials of flammable fluids must receive special attention, since they generally are the major volume of such material.

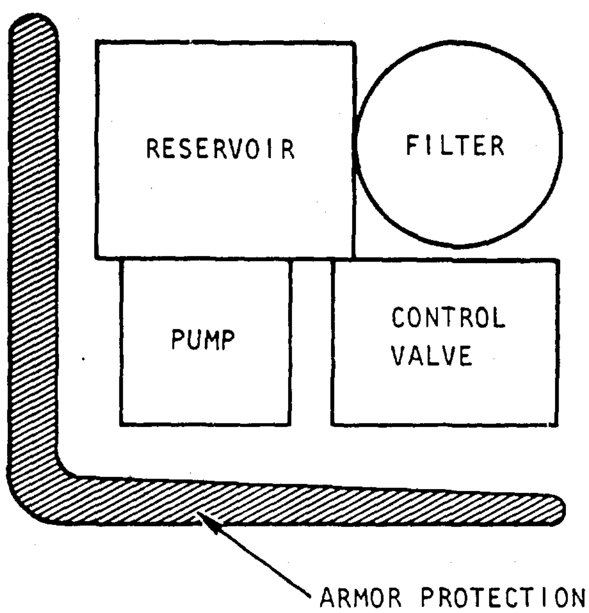


Figure 31. Concentration and Shielding Concept.

Fuel tanks should be located so that leakage from ballistic damage will not migrate to the interior of the aircraft or to potential ignition sources such as hot engine sections, hot bleed air lines, or electrical equipment. Batteries should be located in areas where their corrosive acid will not affect personnel or essential elements. Explosives, such as ammunition, rockets, and grenades, should be located so as to minimize injury or damage to the crew or equipment if struck. Provisions should be considered for rapid jettisoning of such material if containment of their response is not feasible.

4.2.2.2.5 Minimized Detection: Enemy forces must detect an aircraft before they can use their weapons against it. Minimizing those factors that contribute to aircraft detection can significantly degrade the effectiveness of hostile small-arm forces that rely upon visual and audible cues to detect an aircraft. In minimizing detection, there are a number of techniques that apply to overall aircraft configuration design features that must be considered at the initial design stage. The specific information and guidance in this area are contained in Chapter 3.

4.3 STRUCTURES

4.3.1 INTRODUCTION

The airframe is the basic structure subsystem within an aircraft system and consists of the fuselage, rotary wings, fixed wings, empennage, landing gear, pylons, and external stores. The airframe is, in general, the least sensitive portion of the aircraft to small-arms fire. It is designed in accordance with Military Specifications MIL-S-8698 and MIL-A-8861 (ASG). There are, however, specific aircraft design considerations (crashworthiness, reparability, secondary hazards, and operational readiness) that can significantly influence the effectiveness of the system. These considerations must be taken into account in the initial design phase to select the basic structural type, or combination of types, that will provide the most survivable and effective system configuration. Design criteria presented in Paragraph 4.3 of USAAVLABS TR 70-22 will be used as the basic criteria for crashworthiness design of the aircraft.[33]

The passive defense capability of the airframe is derived from its physical tolerance of ballistic (small-arms fire) impact damage. Structural survivability to larger high-explosive projectiles requires careful design consideration as well to insure maximum effectiveness of design. Designer ingenuity, subsystem integration, and the application of passive defense measures are the keys to a survivable aircraft weapon system.

4.3.2 BALLISTIC DAMAGE EFFECTS

Aircraft structure can be damaged by the primary or secondary damage mechanisms that may be caused by hostile small-arms weapon effects. The primary damage mechanism is penetration of the structure by a projectile. The response of the structure is dependent upon the size, impact velocity, and attitude of the projectile, together with the structural material properties, construction, and operational stresses. For a straight-in penetration (normal to the surface) of ductile metal, such as aluminum alloy, the entry hole would be approximately the same size as the projectile. Figure 32 shows the penetration of a typical aluminum alloy skin by a .50 caliber projectile while under simulated operating loads. The damage is restricted to a clean hole with back surface "petalling" and no crack propagation. The exit damage in this type of construction is dependent upon the attitude (yaw angle) of the projectile and the type of intervening structure and/or components that are also penetrated. Figure 33 shows typical exit damage from a "tumbled" projectile.

The angle of projectile penetration (obliquity) can also influence the degree of damage sustained. Figure 34 shows an extreme case where the projectile path was nearly parallel with the structural skin, and a long path of damage was experienced.

More brittle materials, such as 7075-T6 aluminum, that might be used for high stress applications are susceptible to extensive damage from crack propagation, an example of which is shown in Figure 35, where large triskelion cracks were experienced.

Transparencies used for aircraft structures are also susceptible to damage from small-arms fire. The extent of such damage is a function of the material properties, construction, and operating stresses. Cast and stretched acrylics tend to crack or shatter from impact and tear out sections. Polycarbonates are more resistant to such damage propagation. Ballistic-resistant transparencies, such as bullet-resistant glass, are generally fabricated in layers with flexible adhesives between them. Such configurations tend to experience "spidering" cracks from ballistic impact and/or penetration. Examples of this type of damage are shown in Figure 36.

Sandwich structure, such as honeycomb material contained between face sheets, responds to ballistic impact generally as shown in Figures 37 and 38. Deformation of the face sheets is typical of thin-skin materials. Delamination of the honeycomb core from the face sheets is also experienced. Figure 39 illustrates the level of damage encountered with low grazing angle hits in the honeycomb panel structure. Extensive

Figure 32. Aluminum Skin Projectile Damage Normal Entry.

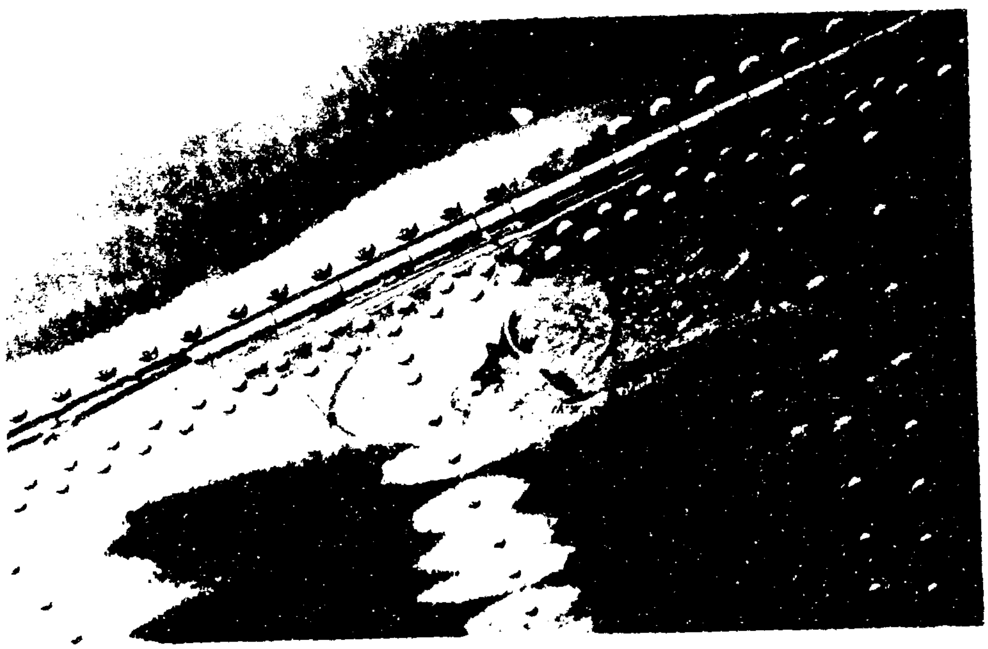


Figure 33. Tumbled Projectile Exit Damage.

Figure 34. Structural Skin Damage (Projectile High Obliquity).

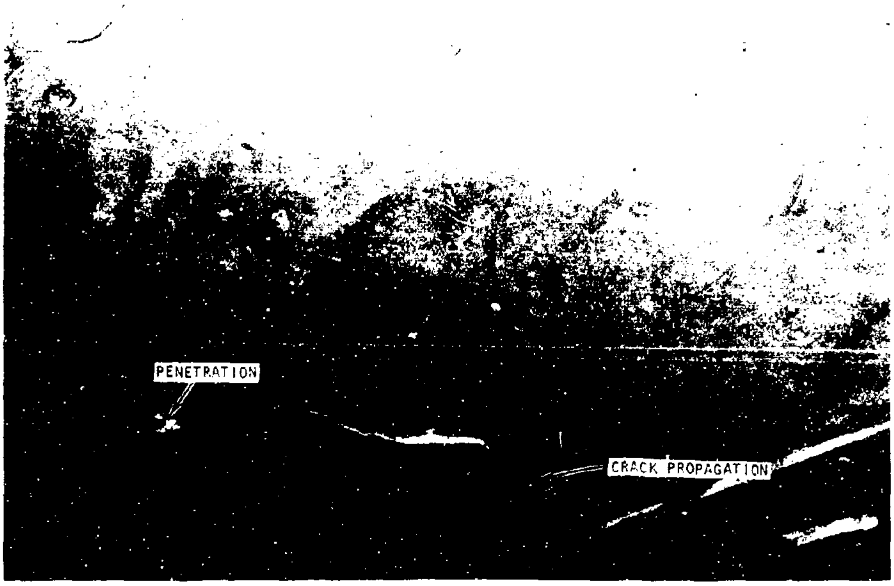


Figure 35. Brittle Material Ballistic Effect Crack Propagation.

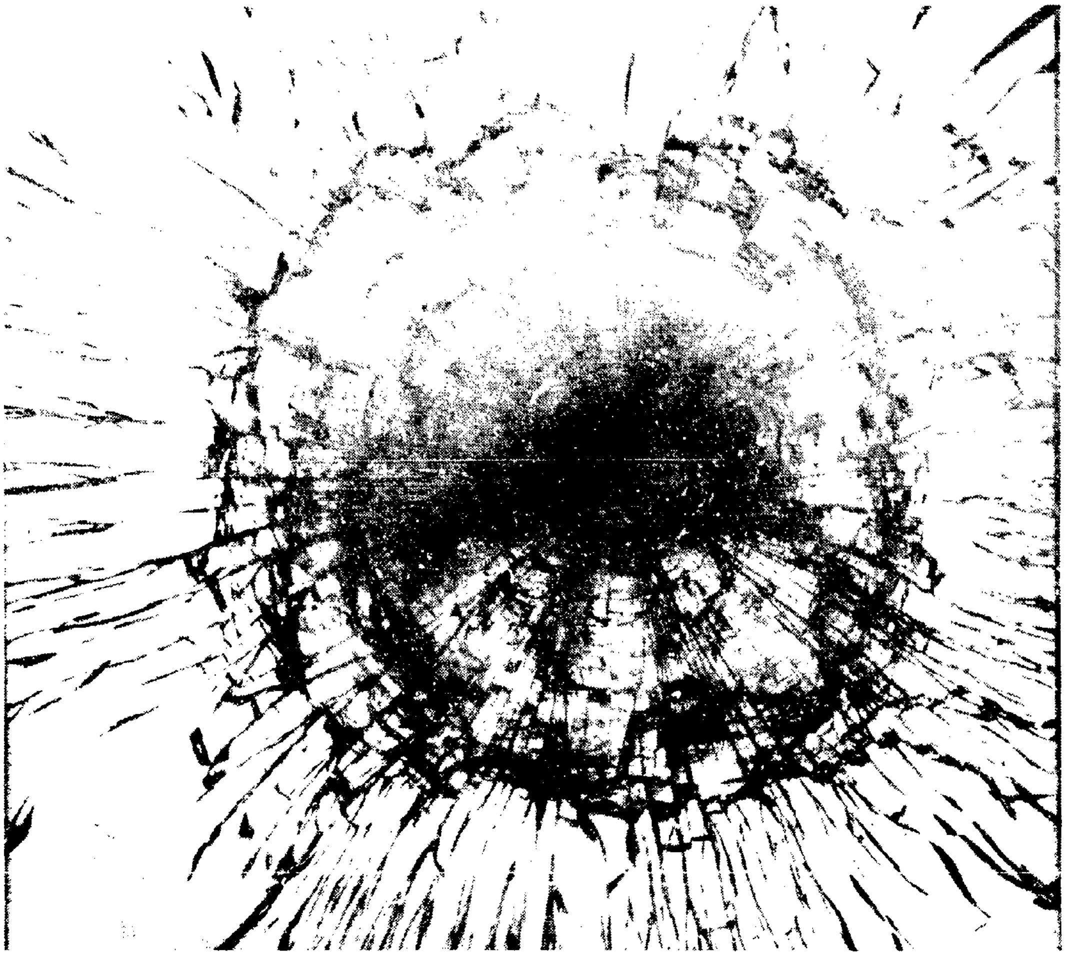


Figure 36. "Spidering" Effect Ballistic Impact Damage to Ballistic-Resistant Transparency Test Sample.

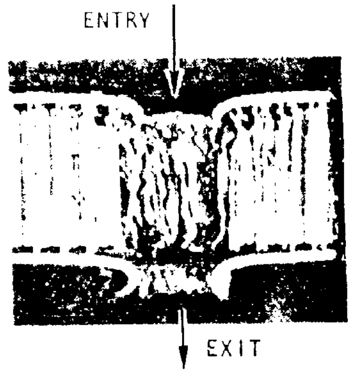


Figure 37. Honeycomb Panel Damage 0°.

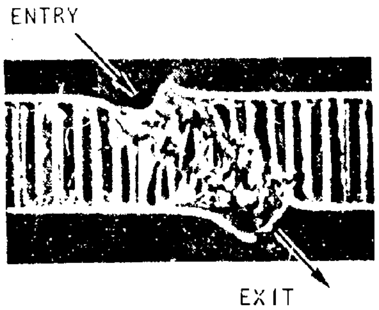


Figure 38. Honeycomb Panel Damage 45° Obliquity.

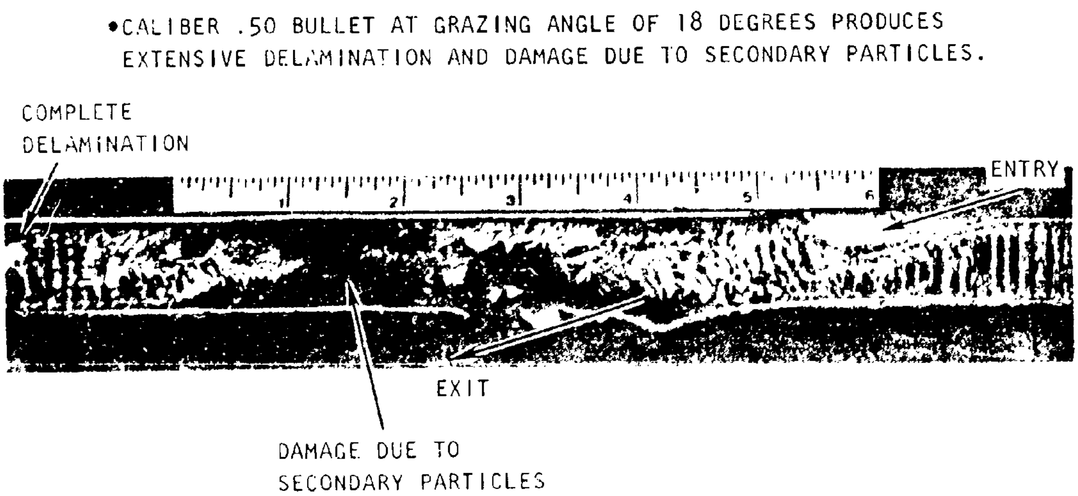


Figure 39. Honeycomb Panel Damage 72° Obliquity.

delamination is experienced beyond the exit hole in addition to core damage from secondary particles.

Secondary damage effects are those not directly caused by ballistic impact but by initiation of a response or condition from another element within the air vehicle. Spallation and debris generated by a projectile penetration of structure may cause secondary damage to sensitive elements. Liberation and ignition of flammable fluids or vapors can cause fire or explosion conditions that can seriously damage the airframe. High thermal conditions may also be generated by ballistic damage to engine hot sections or hot air bleed lines. This can produce hot gas "torching" effects that may degrade the structure's capability to adequately carry operational loads or cause distortions that, in turn, can affect the capability of other subsystems to operate.

Projectile impact into structural sections containing liquids, such as fuel, creates a liquid pressure pulse or "hydraulic ram" effect that is transmitted directly to the supporting structure. Depending upon the size and kinetic impact energy of the projectile, cracking, bulging, or rupture of the structure can occur.

4.3.3 GENERAL DESIGN CONSIDERATIONS

Generally, small-arms weapon damage to aircraft structure will not cause loss of the aircraft or appreciably affect its capability to fly. There are a number of factors that must be considered to insure that newly developed materials and construction concepts are employed in a manner that does not adversely affect survivability of the aircraft. The following are basic design factors that should be carefully considered in the initial design process where basic structural configurations are defined.[28-33]

4.3.3.1 Material Selection: When selecting aircraft structure material, it is important to use those with good fracture-toughness qualities to prevent and/or minimize crack propagation from small-arms damage. The critical plane strain-stress intensity factor (K_{Ic}) is used in the field of fracture mechanics as a fracture index. Material type, heat-treat condition, and grain direction are variables that influence its capability to resist crack growth. Fracture mechanics is a relatively new technical discipline and, as such, must rely upon physical tests rather than pure analytical means to determine the crack resistance of specific structural designs after ballistic damage. Table VI is a listing of some typical types of airframe construction materials with their typical and minimum fracture indexes (K_{Ic}) for longitudinal and transverse grain directions at

TABLE VI. ROOM TEMPERATURE FRACTURE-TOUGHNESS PROPERTIES

Material	Condition	Typical K_{Ic} (KSI x $\sqrt{\ell}$) L	Typical K_{Ic} (KSI x $\sqrt{\ell}$) T	Minimum K_{Ic} (KSI x $\sqrt{\ell}$) L	Minimum K_{Ic} (KSI x $\sqrt{\ell}$) T
2024 Aluminum Alloy	-T3X and -T4X	40	35	27	23
	-T6X and -T8X	25	19	17	13
7075 Aluminum Alloy	-T6X	24	21	17	14
	-T76X	27	25	20	18
	-T73	30	26	21	18
6Al-4V Titanium	Cond A	60	60	40	40
	Diffusion Bonded	75	75	50	50
9Ni-4Co-0.30C Steel	220 KSI Min Ult.	110	110	73	73
PH13-8Mo Corrosion-Resistant Steel	H1000	90	90	60	60
	H1100	110	110	73	73

L = Longitudinal grain direction

T = Transverse grain direction

K_{Ic} = Critical plane-strain-stress intensity factor

ℓ = Crack length in inches

room temperature. The values shown are for thousands of pounds per square inch stress (ksi) times the square root of the crack length ($\sqrt{l}$) in inches. For example, for 2024-T3X aluminum alloy material with a 1-inch crack, a longitudinal stress of over 40,000 psi will cause crack growth.

4.3.3.2 Basic Design Concepts: Three basic types of construction can be used for aircraft structures: thin skin/stringer, sandwich, and sculptured plate. The selection of construction type for each major structural element, i.e., fuselage, rotary wing, fixed wing, empennage, and tail rotor, must consider the type and level of damage by hostile small-arms weapon effects that can be tolerated.

Thin skin/stringer construction provides more ballistic damage tolerance than other types of construction when ductile, high-fracture-toughness materials are used. Multiload-path construction should be used to allow fail-safe response of the structure if damaged. Wide, large-area stringers, frames, and longerons should be used in preference to heavy-section small-area types that can lose a larger percentage of load-carrying capability when struck by a projectile. Attachments for the transfer of high loads should be designed for adequate strength following ballistic damage to permit safe recovery of the aircraft under combat maneuvering conditions.

Sandwich construction includes fabrication by bonding of face sheets to an inside core. Honeycomb construction is one of the most widely used types of sandwich construction. Fiber glass or plastic material laminates are examples that have been under recent development and use. Composites, such as boron filaments bonded with epoxy resins, have been under research and development for new aircraft structure since they offer high strength-to-weight ratios that are needed for higher performance requirements. Graphite fibers are also under development as a new construction material. Selection of the basic material for sandwich construction must consider the strength remaining in the load-carrying elements when subjected to single- and multiple-projectile impacts.

Sculptured plate (integrally stiffened) structure is fabricated from one piece of material by mechanical, electrical, or chemical means. Material is removed to leave relatively thin walls integral with heavier stiffening lands and attachment sections. This type of construction is generally used for highly loaded panels or "shell-like" applications. This type of construction should be used with discretion due to the potential danger of extensive crack propagation and the limited combat area reparability characteristics. Experience with sculptured plate construction has shown that small-arms fire damage has required the replacement of major structural elements where such damage levels in skin/stringer and sandwich-type construction were easily repaired.

Careful selection of the basic material and its heat treatment is essential to obtain good fracture-toughness characteristics for the specific application that will prevent or minimize crack propagation.

4.3.3.3 Major Element Replacement: Extensive damage can be sustained by aircraft structures from the indirect effects of enemy gunfire. Forced or crash landings can be caused by damage to flight-essential subsystems. Consideration should be given to design concepts that will permit easy removal and replacement of major structural elements to facilitate rapid combat area repair and return of the aircraft to operational status. Figure 40 shows an example of a helicopter with lower fuselage damage. Figure 41 shows the replacement section for the aircraft prior to installation. Interchangeability of major structural sections should also be considered to permit rapid repair by cannibalization of damaged aircraft.

4.3.3.4 Crashworthiness Interrelationships: Structural survivability design features must be fully integrated with crashworthiness considerations. This includes multiload-path and fail-safe features as well as considerations for natural "masking" of vital components and personnel from small-arms projectiles. This is particularly important in providing a living space for occupants under crash conditions. The application of parasitic armor on structure must also consider methods to prevent their tearing loose under crash conditions and becoming lethal missiles that could injure the occupants or rupture otherwise crashworthy fuel tanks. The Army's Crash Survival Design Guide, USAAVLABS TR 70-22, shall be used for integrated design efforts.[33]

4.3.4 DETAIL DESIGN CONSIDERATIONS

The majority of aircraft structural design considerations for survivability enhancement against small-arms weapon effects are applicable to almost all portions of the airframe. These considerations apply to three types of construction: thin skin/stringer, sandwich, and sculptured plate. Each has been used for fuselage, wing, and empennage construction. Helicopter main rotor and tail rotor blades, however, are in a special category that must be considered individually. Thus, they are addressed separately in this section.

4.3.4.1 Thin Skin/Stringer Construction: The following techniques for minimizing the consequences of small-arms projectile impacts on thin skin/stringer type structures should be considered:

- Select materials with high fracture-toughness values to minimize and/or prevent crack propagation following ballistic damage.

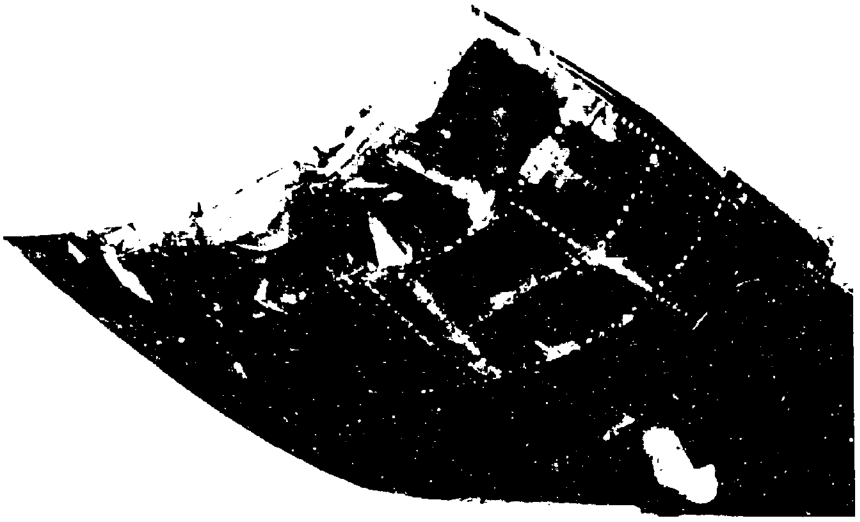


Figure 40. Helicopter With Damaged Fuselage.

Figure 41. Helicopter Replacement Fuselage Section.

- Consider the use of bonded "doublers" on high-strength stressed skin panels, such as 7075-T6 aluminum alloy, that may be susceptible to catastrophic failure from a single hit by a small-arms projectile. A crack can be arrested by placing a number of fibers across a given zone of stress normal to the line of expected crack direction, thus reducing the stress intensity below the level required to propagate the crack. A thin layer "strap" of fiber glass can be bonded in proximity to the skin to provide such protection. Test programs have shown that a significant improvement in crack arrest can be achieved for very modest penalties. Figure 42 illustrates placement of thin fiber glass tape on a typical high-stress panel to provide a crack-arrest feature.[28]

4.3.4.2 <u>Sandwich Construction</u>: The following techniques for minimizing damage from small-arms projectile impacts on sandwich construction should be considered:

- Provide high-strength face sheet to inner core bonding material in areas where fuel or other liquids are carried to prevent or minimize delamination from liquid pressure pulse (hydraulic ram) effects caused by ballistic impacts.

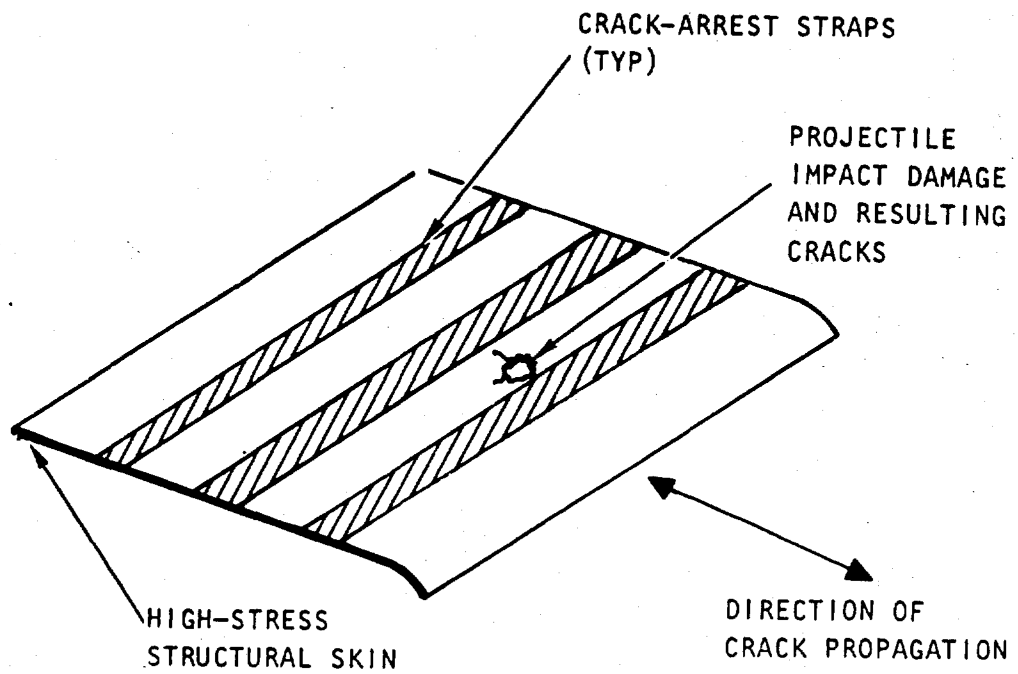


Figure 42. Crack-Arrest Straps.

- Consider the use of "planking" construction techniques to limit face sheet delamination from core material as a result of projectile impacts.

- Use high-temperature-tolerant bonding materials in areas where short-term fires or high-temperature air can be experienced from small-arms damage, to minimize loss of structural integrity.

4.3.4.3 Sculptured Plate Construction: Where sculptured plate construction is used, the following design techniques should be considered:

- Use materials with high fracture-toughness characteristics to resist crack propagation from ballistic damage. For example, use 2024-T4 aluminum alloy in place of higher strength, but more brittle, 7075-T6 aluminum alloy. Select heat-treat condition of material to obtain good fracture-toughness values.

- Use "planking" construction for structural areas primarily under tension-type loads to limit crack propagation from battle damage.

- Avoid straight lines of fasteners over large sections subject to high stress loads to limit rapid "zippering" effects due to projectile damage.

- Design sculptured sections with large radii and avoid abrupt changes in sections where ballistic impact energies can develop high stress concentrations.

4.3.4.4 Rotary-Wing Design: Helicopter rotor blades represent a significant part of the total area that may be subjected to hostile small-arms fire. It can be expected, therefore, that a high percentage of projectile hits will be experienced by the rotor blades. Combat experience to date has indicated that the vulnerability of current metal blades to such small-arms weapon effects is not serious. However, blade vulnerability is an area that must not be overlooked in new helicopter designs since new construction concepts and materials may not exhibit the same tolerance to battle damage. The four major types of blade design, depicted in Figure 43, are (1) steel spar with fiber glass skin, (2) aluminum spar with aluminum skin, (3) aluminum spar with aluminum honeycomb filler and sheet metal skin, and (4) plastic fiber glass shell with aluminum honeycomb filler. Consideration must be given to the evaluation of the time remaining after a hit for the effects of crack propagation to insure that stress levels will not be excessive. Figure 44 illustrates the type of S-N curve data that must be considered for a typical rotor blade configuration.[29]

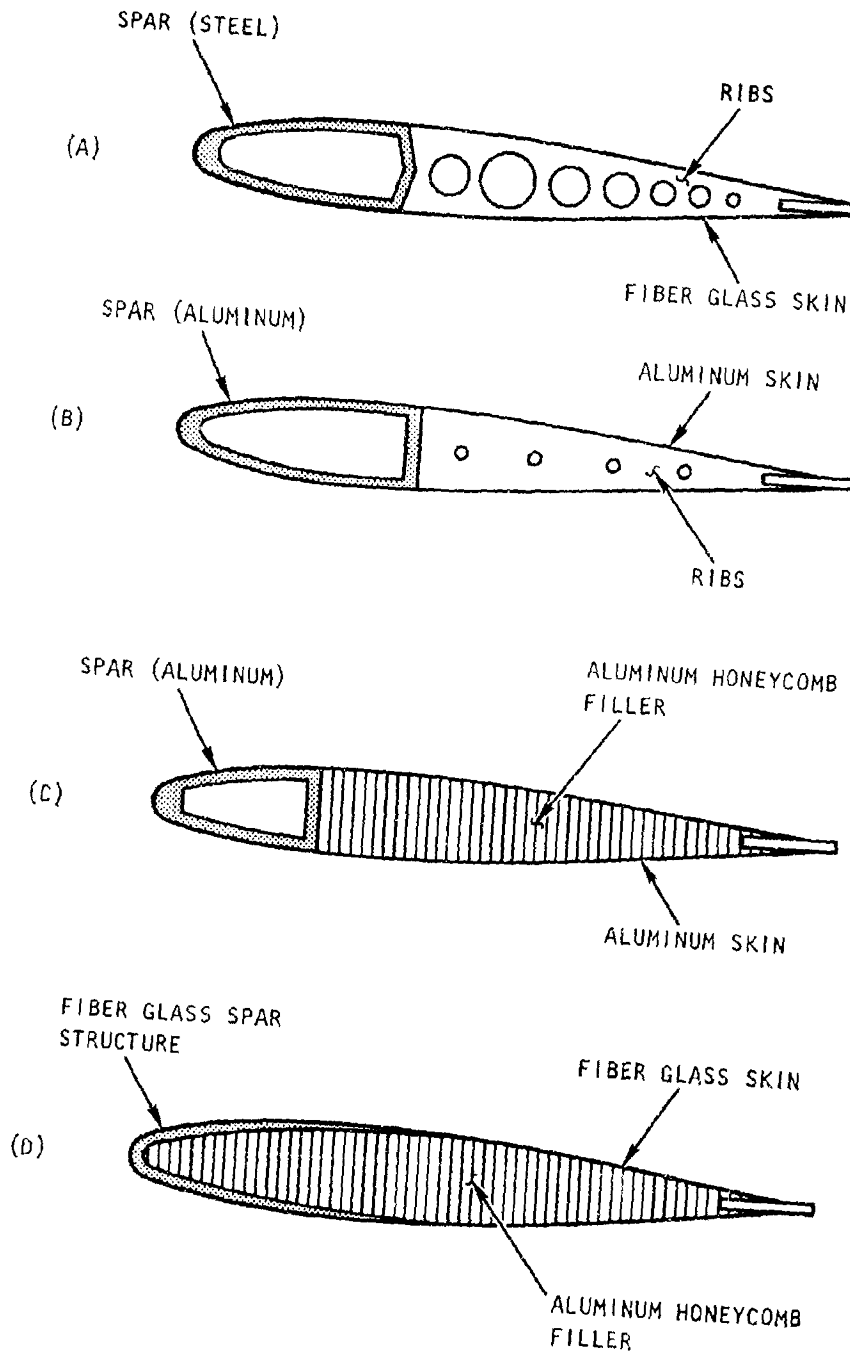


Figure 43. Major Types of Blade Design.

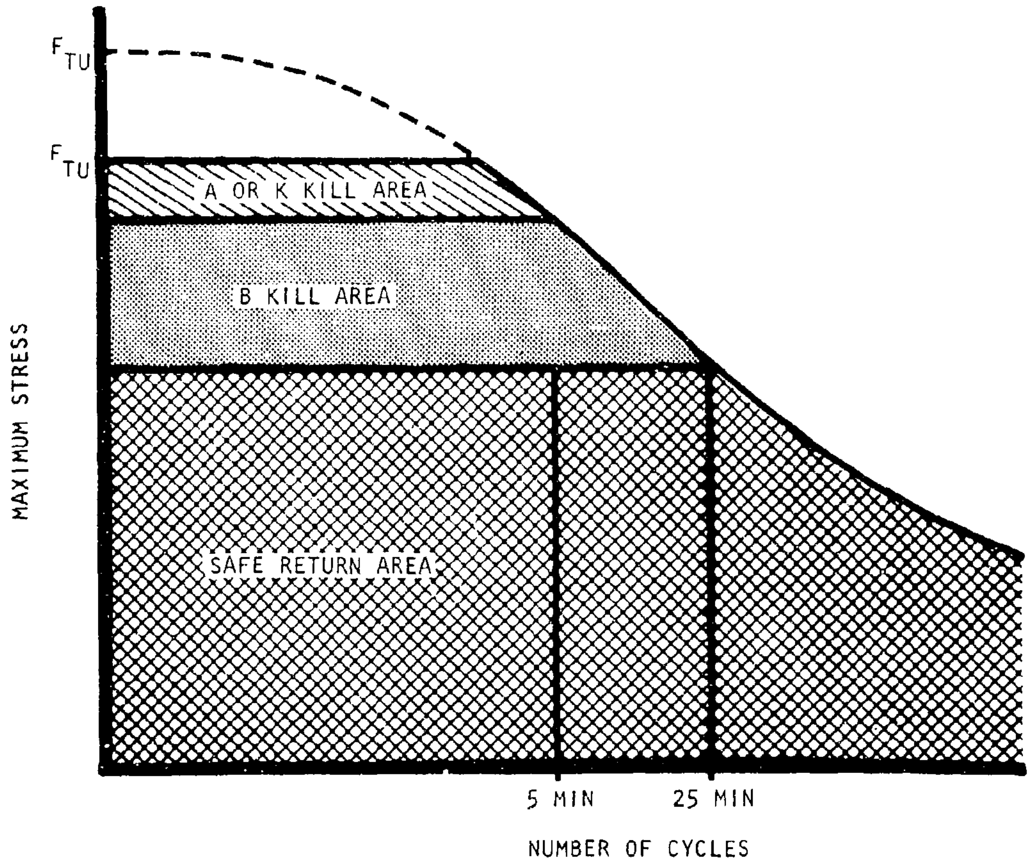


Figure 44. Typical Rotor Blade S-N Curve.

The development of composite materials has opened up an area where rotor blade concepts are certain to be changed. Significant improvements in performance and cost are expected to be realized, as shown in Figure 45.

Full-scale boron composite rotor blades have been fabricated. Figure 46 shows the general construction details of a design concept for the CH-47 helicopter. For blades constructed from the composite materials, allowances must be made for reasonable amounts of projectile damage, considering both single and multiple hit possibilities, to insure that adequate strength will remain for recovery of the aircraft. Considerations must also be directed toward the techniques and efforts that will be required to repair ballistic damage of composite material construction so that high replacement rates of blades are avoided and combat area repairs are easily accomplished.[30]

4.3.4.5 Tail Rotor Design: Helicopter tail rotor blades are relatively insensitive to small-arms weapon effects except when struck in those small areas where bearings and control linkages attach. In such instances, large unbalance conditions can occur that may cause failure of the assembly and create secondary missiles that are hazardous to the rest of the aircraft. Failure of the tail rotor system may cause mission abort, a forced landing, or a crash, depending upon the specific aircraft and operating environment.

The basic design principles contained in the preceding paragraphs on main rotor blade design also apply to tail rotor configurations. In addition to those design techniques, there is an additional one that applies only to tail rotors - a design concept to use a "torsion pitch control" technique to minimize the vulnerability of a tail rotor system. Figure 47 illustrates its basic principles. A "torque tube" is bonded at its end to the interior of the rotor blade. A flexible collar is used to permit angular pitch adjustment by control linkage input that "twists" the torque tube. Considerable ballistic damage can be sustained by this type of construction without loss of operational capability. Complete loss of the rotor blade is virtually impossible because of the large areas of tube attachment to the blade and the inherent stability that would be present if the control linkage attachment were severed.

4.4 PERSONNEL STATIONS

4.4.1 INTRODUCTION

Aircraft crew performance and survival are major design considerations when related to a hostile environment caused by small-arms fire. Pilots,

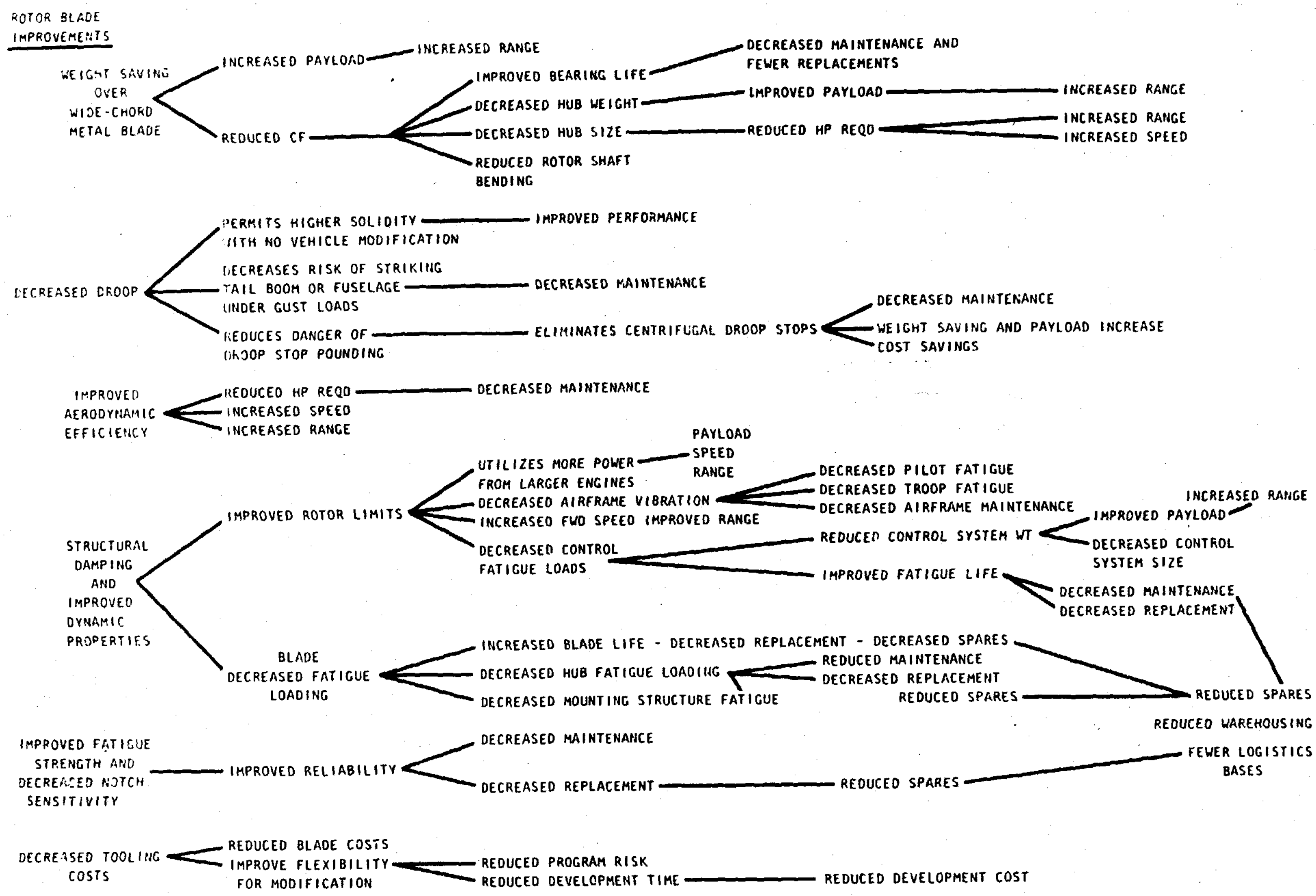


Figure 45. Cascading Effects of Rotor Blade Improvement.

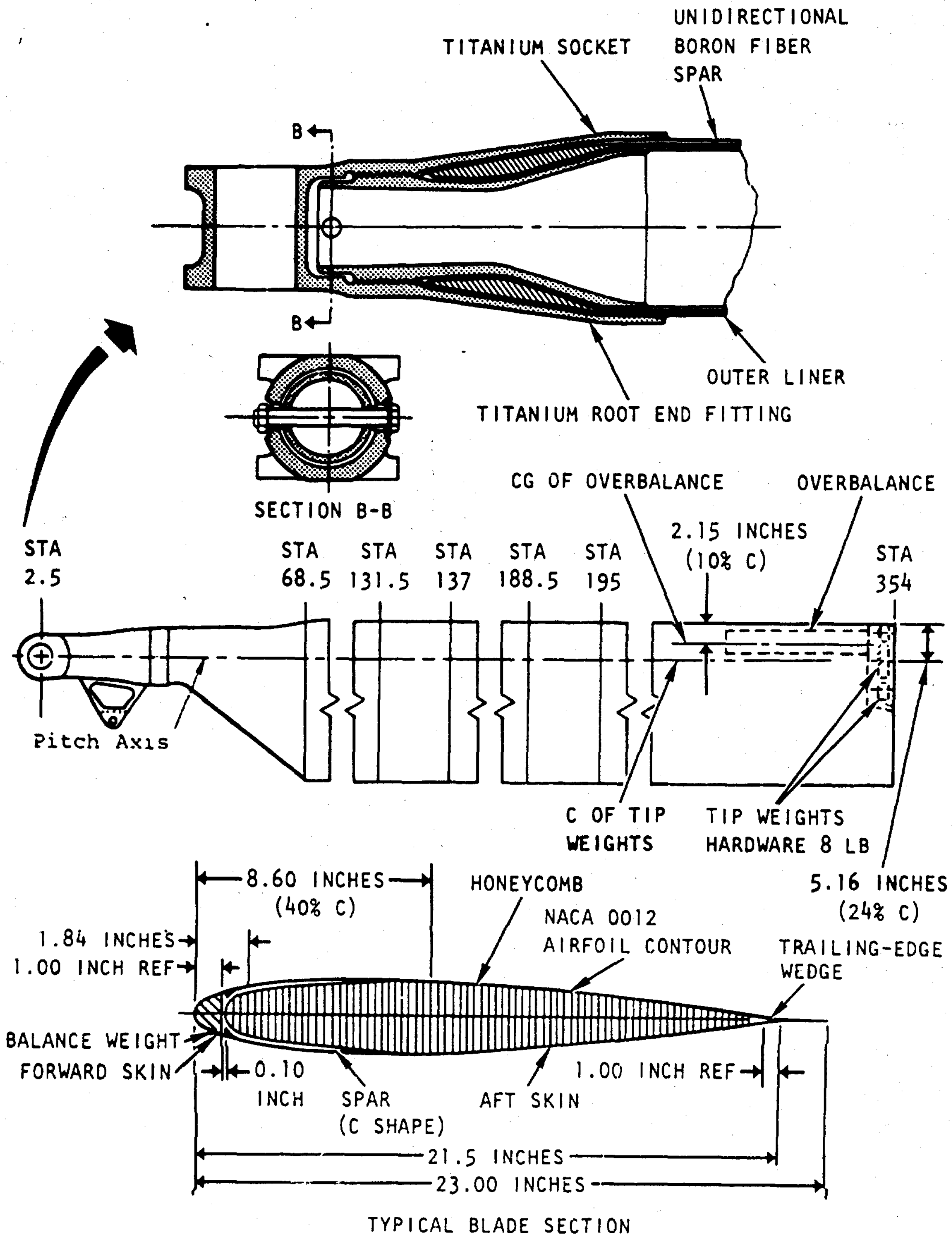


Figure 46. Composite C-Spar of CH-47 Blade Configuration.

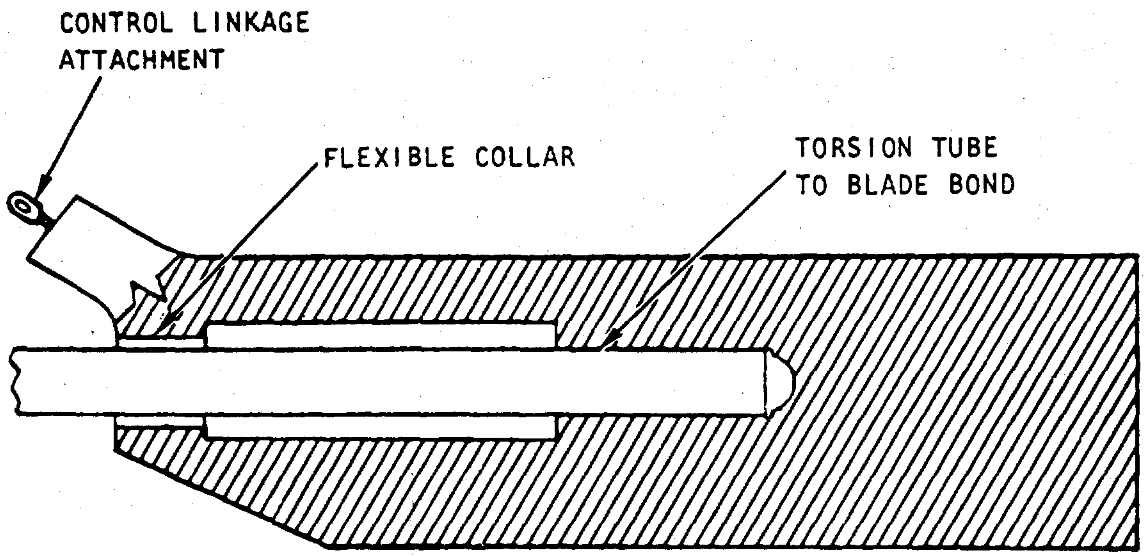


Figure 47. Torsion Pitch Control Tail Rotor Concept.

crewmembers, and passengers are susceptible to a number of direct and secondary weapon effects that can cause mission failure and loss of aircraft:

- Penetration and trauma due to projectiles, fragments, and secondary spallation

- Penetration, injury, and trauma due to fire, explosive decompression, and crash impacts

- Loss of consciousness due to loss of pressurization and loss of oxygen.

- Degradation of aircrew operating capability due to smoke, fire, or toxic materials created by small-arms fire

The specific threats that the crew and aircraft occupants will be exposed to during the aircraft's mission profiles must be carefully considered early in the design phase and continually throughout the design cycle. The survivability enhancement design techniques that will provide the optimum protection consistent with the required mission performance must be carefully chosen and applied as early in the design cycle as possible. Advances in personnel protection techniques are being introduced continually in various Government and industry activities.[33-59]

4.4.2 DISCUSSION

Aircrews are quite vulnerable to small-arms fire in today's combat environment. However, more aircrews are killed in aircraft crashes caused by weapon effects than by direct hits from the weapons themselves. Therefore, man must be protected from hostile small-arms weapon effects and from the intolerable stresses that he may suffer in a crash. USAAVLABS Technical Report 70-22, "Crash Survival Design Guide," is to be used in developing designs and modifications for crashworthy U.S. Army aircraft and subsystems.[33] Reduction in crew vulnerability due to crash impact requires interface with other subsystems to reduce fires in-flight, to protect the critical control system, and to prevent oil starvation. A systems engineering approach to the design of the airframe, floor, seat attachments, seat frame, etc., must be used and must include the inertial effect of armor, including body armor, under crash conditions.

Head, neck, and torso wounds are the most prevalent wounds which result in the largest number of fatalities among wounded aircrews. Current data indicates that full armor protection against small-arms fire cannot be provided without compromising the efficiency of the crew. Present-day concepts of armor conflict with pilot mobility and vision requirements. Body armor placed on an aircrew member imposes many physiological and mechanical penalties. Thus, it behooves the designer to minimize the vulnerability of the air vehicle and the aircrew by means other than placing armor on or around the aircrew member, or to develop new armor concepts and applications.[34-36]

Secondary injury caused by body armor during a crash can result in serious injury and/or fatalities. The weight of a ballistic helmet imposes a serious threat to the human neck structure during an aircraft crash. Impact between the head and armor can occur when weapon effects result in excessive forces on the man or on his protective equipment.

It is impractical, with current technology, to protect the aircrew with body armor against projectiles larger than the .30 caliber and equivalent fragments since the impact energy transmitted to the human body by .50 caliber projectiles or larger would be fatal. Modular armor concepts need to be considered to provide different levels of protection against projectile and equivalent fragments up to the .50 caliber size. The use of armor materials as cockpit structure should perform a dual function, i.e., provide protection for a critical component as well as the aircrew. An attempt should be made to place equipment in the cockpit so that it provides natural masking without degrading the efficiency of the crew and the aircraft. Weight penalties that are accumulated because of the provisions for crew protection should be included in the summation of the empty weight of the aircraft.

4.4.3 DESIGN CRITERIA FOR CREW STATIONS AND PASSENGER COMPARTMENTS

The designer of equipment for aircrews and passengers must continually consider basic problems of human behavior. It is especially important to remember that a design may inherently possess all of the classical human engineering characteristics known to man but, if it is not capable of performing the stated mission(s), it is operationally unsuitable. In addition, ease of maintenance must be considered. Army personnel must be able to maintain the item with the equipment that is available in the field.

The following paragraphs present solutions to specific problems when possible. In areas where insufficient design data are available, only the general philosophy that is appropriate to the solution of the problem is presented. The details of these solutions, as well as the degree of reduced vulnerability or enhanced survivability to be achieved, must be considered, and the merits or benefits of each evaluated by trade-off studies.

4.4.3.1 Crewmembers and Passengers: Both operating aircrew members and passengers are vulnerable to projectiles and to spall and debris created by the projectiles as they penetrate parts of the aircraft. A man's vulnerable areas are his head, the primary organs within his chest and abdomen, and the larger arteries and veins of his extremities.[35-36]

Information and data pertaining to weapon effects on crewmembers and passengers are difficult to analyze for several reasons:

- Data collection to the depth desired is often operationally impractical.
- In the confusion of combat, it is difficult to identify weapons, ranges, angles of obliquity, etc.
- Tests must be conducted in a humane manner on animals or simulated dummies.

Lethality criteria are developed from experimental investigations with test animals and are correlated with human structure on a medical basis. Systematic, experimental, wound-ballistic programs to supply data for the studies are carried out at the U.S. Army Medical Center.

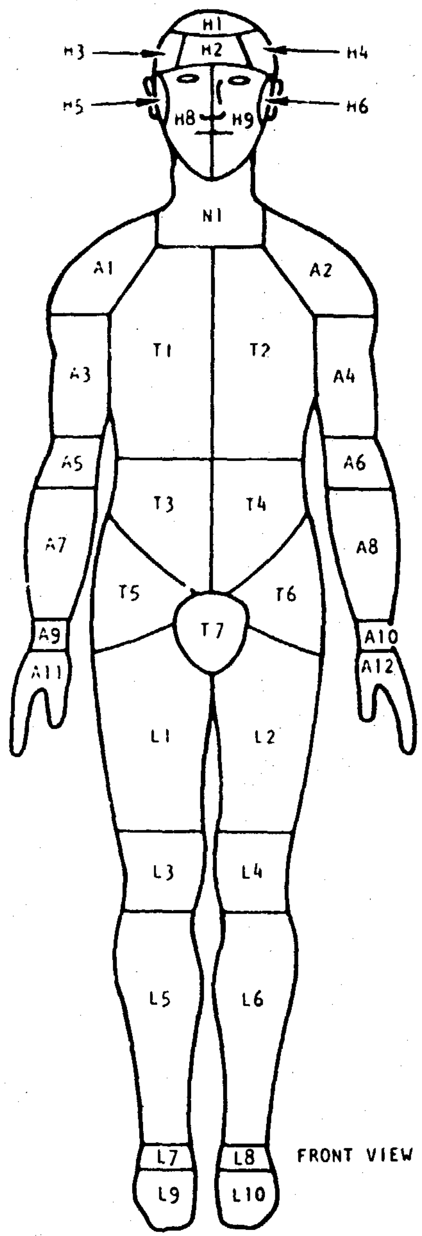
A typical report analyzes combat casualties to U.S. Army personnel aboard Army aircraft. An attempt was made to exclude casualties from (pure) accidents not involving ground-fire hits. The main objective of the study was to identify and define the different types of casualties that occurred,

their causes, their frequency, and the attendant encounter circumstances (both qualitatively and quantitatively) as fully as possible. The casualty types, locations, and causes identified the areas of concern. The relative frequency of the various casualty occurrences provides the proper perspective for the designer to minimize casualties for similar aircraft. Figure 48 provides an effective method for mapping the human body when performing these types of studies.

The human body is composed of soft, pliable tissues surrounding a comparatively soft and brittle skeletal structure. (See Figure 49.) This entire mass contains blood vessels that release life-preserving fluids when punctured and nerves that relay paralyzing and fatal shock signals when damaged. Predicting the probability of kill, when given a hit ($P_{K/H}$), on an aircrewman becomes a rather tenuous engineering guessing game. Some examples of weapon effects are cited that may give the designer, in concert with the medical and life science specialists, a reasonable foundation for performing vulnerability analyses and arriving at tenable conclusions. At present, there is no standard or precise means to equate casualty criteria to projectile types and impact energies.

The following is an extract of actual combat wound experiences that provide the designer with an indication of human vulnerability:

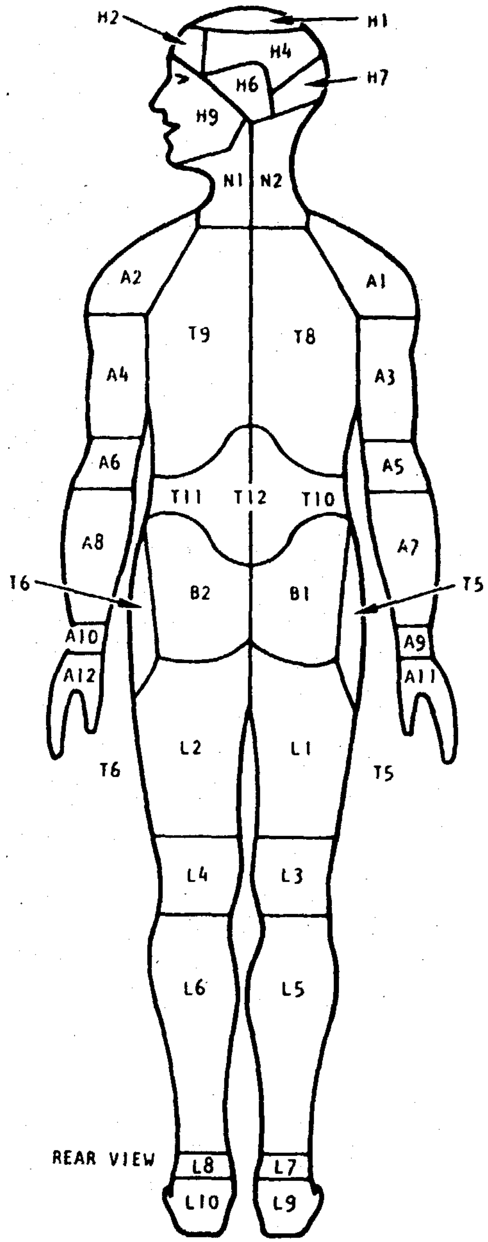
- A 5.56 mm projectile fragmented when it hit a bone.
- A 5.56 x 0.45 mm projectile pierced the chest cavity near the heart at a range of 100 feet.
- A 7.62 x 0.39 mm projectile pierced the chest cavity, perforated a lung, and fractured a rib at a range of 150 to 225 feet.
- Bullet (projectile) wounds of the vital chest structures are more severe than those caused by fragments.
- In fatalities caused by weapon effects, injuries to the vital structures of the thorax occur in direct proportion to the amount of space occupied by the structures. The lungs are injured more than any other chest structure, followed by the heart and the thoracic blood vessels.
- Penetrating missile injuries of the heart and the major blood vessels are most likely to be fatal.
- Ribs are injured in approximately 50 percent of the fatalities.



FRONT VIEW

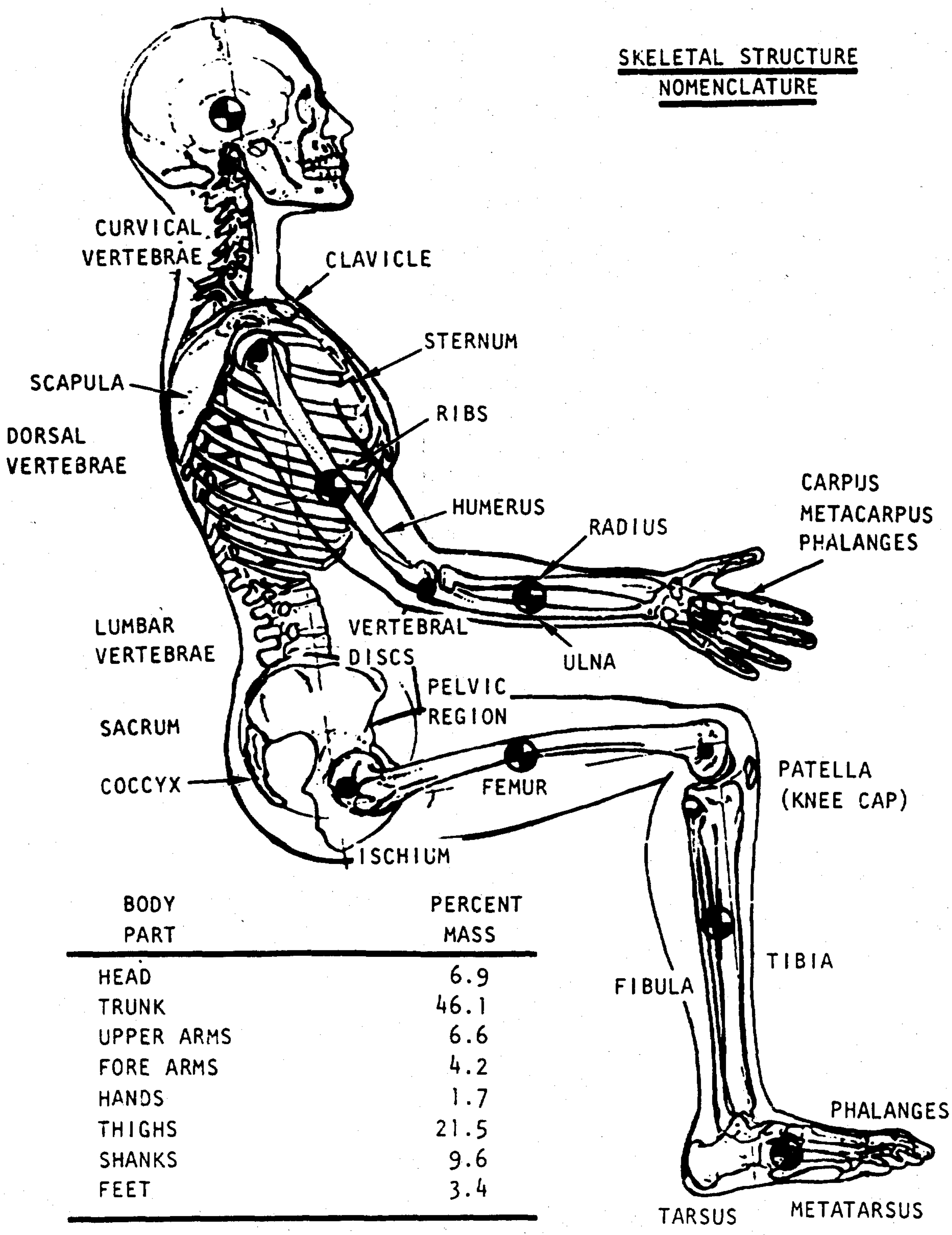
LOCATION	SIDE	SYMBOLS
HEAD & NECK		
TOP	NA	H1
FOREHEAD	NA	H2
SKULL (1)	RIGHT, LEFT, BACK	H3, H4, H7
MASTOID	RIGHT, LEFT	H5, H6
FACE	RIGHT, LEFT	H8, H9
NECK (2)	FRONT, BACK	N1, N2
TORSO (FRONT)		
CHEST	RIGHT, LEFT	T1, T2
ABDOMEN	RIGHT, LEFT	T3, T4
HIP	RIGHT, LEFT	T5, T6
GROIN	NA	T7
TORSO (REAR)		
HIP	RIGHT, LEFT	T5, T6
BACK	RIGHT, LEFT	T8, T9
LUMBAR	RIGHT, LEFT	T10, T11
SPINE (1)	NA	T12
BUTTOCKS	RIGHT, LEFT	B1, B2
ARM		
SHOULDER	RIGHT, LEFT	A1, A2
UPPER	RIGHT, LEFT	A3, A4
ELBOW	RIGHT, LEFT	A5, A6
LOWER	RIGHT, LEFT	A7, A8
WRIST	RIGHT, LEFT	A9, A10
HAND	RIGHT, LEFT	A11, A12
LEG		
UPPER	RIGHT, LEFT	L1, L2
KNEE	RIGHT, LEFT	L3, L4
LOWER	RIGHT, LEFT	L5, L6
ANKLE	RIGHT, LEFT	L7, L8
FOOT (INCL. HEEL)	RIGHT, LEFT	L9, L10

NOTES
1 - NO FRONT SIDE FOR SKULL OR SPINE
2 - NO LEFT OR RIGHT SIDE FOR NECK, SPINE, OR FOREHEAD



REAR VIEW

Figure 48. Human Body Zones.



BODY PART	PERCENT MASS
HEAD	6.9
TRUNK	46.1
UPPER ARMS	6.6
FORE ARMS	4.2
HANDS	1.7
THIGHS	21.5
SHANKS	9.6
FEET	3.4
TOTAL	100.0

Figure 49. Human Skeletal Structure.

- In thorax-abdominal injuries, the liver and spleen are most frequently injured, followed by the stomach and kidneys.

4.4.3.2 Aircrew Redundancy/Separation: It is necessary to provide as much separation or shielding as practical between multiple pilot stations to prevent or minimize aircraft loss or mission failure due to a single weapon penetration of a crew station. For example, two pilots, not shielded from each other, may both be fatally injured from penetration of the crew compartment by a projectile. Fatal injury may also occur due to secondary spallation of structure, equipment, armor, etc., when penetrated by a fragment or projectile. Side-by-side pilot seating should be avoided in aircraft where such hazards are prevalent and combat effectiveness will not be degraded.

4.4.3.3 Natural Shielding/Masking: Investigation of the protection afforded personnel by aircraft cabin structure and related equipment is of interest in the study of associated vulnerability problems for the design of new aircraft.[37]

The crew and passengers can be masked from hostile weapon effects by positioning the noncritical or less critical components and elements of the aircraft so that they form a natural shield. Care and engineering judgment must be used to obtain the most protection for the least weight and cost penalties.

Crewmembers should also be masked from accumulators, other pressure vessels, and pyrotechnic or explosive devices which, when damaged by gunfire, will cause secondary damage or injury.

Materials and design configurations (for example, spall shields) that will minimize hazardous spall generation from direct penetration by projectiles or fragments should be used.

When possible, multiload-path thin-section stringers should be used in place of heavy-section longerons in crew stations, that are not capable of defeating the threat, to limit the size and weight of secondary spallation.

Other examples of inherent natural masking/shielding protection media that are found in current Army aircraft include:

- Engines
- Generators
- Transmissions

- Heavy longerons
- Fuel tankage
- Seats and seat supports
- Oil sumps
- Heavy structural fittings

Dense components and/or equipment should be located to provide natural masking from the critical aspect angles so that spallation from projectiles or fragments is minimized.

4.4.3.4 Secondary Fire/Toxic Hazards: One area frequently overlooked in aircraft vulnerability considerations is the creation of secondary hazardous conditions, due to small-arms fire, that can degrade the aircrew's capability to perform their mission duties. Ignition of combustibles within the cockpit area, either by the direct action of an incendiary projectile or the liberation of hot gases, should be considered. A careful and stringent selection of materials used in the aircrew and passenger compartment will provide a low fire potential that minimizes or eliminates the need for an extensive fire protection or other protective system.

Smoke is obviously an irritating substance that is alien to the normal well-being of crewmembers and passengers. Toxins are usually more insidious and can produce an injurious or deadly effect on the human being. Toxic contaminants in an aircraft usually originate from sources such as plastics, lubricating compounds, insulations, paints, cements, and residual solvents from degreasing treatments. Toxins may also be created by the heating of engine and hydraulic fluids. Carbon monoxide is a common contaminant of sealed spaces. High concentrations of carbon dioxide and even oxygen are considered toxic under certain conditions.

The science of toxicology is derived from the disciplines of pharmacology, biochemistry, physiology, anatomy, pathology, industrial hygiene, and medicine. Crew station design engineers should consult with toxicology experts for design guidance in this area. For example, there may be additive effects in mixtures of two products created by a fire condition (synergistic effects, working together of two or more compounds to increase the combined effects beyond simple addition), that by themselves would not be harmful. Toxicological data are often given in terms of a quantity

(dose) or concentration that kills 50 percent of the animals treated. The standard abbreviations are:

- LD 50 (lethal dose for 50 percent)
- LC 50 (lethal concentration for 50 percent)

The following list represents 1-hour permissible limits for exposure to certain compounds. It is emphasized that the limits are the tentatively maximum allowable concentrations permissible under operational conditions and are not permissible limits for repeated short-term exposures. Sufficient time between these peak exposures is assumed to have elapsed to allow complete recovery. In some cases, minor symptomatology may occur.

• Ammonia	400 ppm (parts per million)
• Carbon dioxide	5 percent
• Carbon monoxide	200 ppm
• Hydrogen chloride	50 ppm
• Hydrogen fluoride	5 ppm
• Monoethanolamine	100 ppm
• Oxides of nitrogen	10 ppm
• Ozone	1 ppm
• Phosgene	1 ppm
• Sulfur dioxide	10 ppm

Smoke is extremely complex, and many of its components are known to be toxic. Probably the most thoroughly investigated smoke is that from cigarettes, and over 300 different compounds have been identified in either the particulate phase or in the gas phase. Identified compounds include acids, alcohols, aldehydes, ketones, aliphatic and aromatic hydrocarbons, phenols, nitrogen oxides, ammonia, carbon monoxide, carbon dioxide, hydrogen cyanide, and others. It is unlikely that a fire in an aircraft will produce smoke any less complex than from tobacco.

Combustion of 0.5 to 17.3 grams of material has been made at a temperature of 1,1[illegible] [illegible] and the concentration of the products determined in a volume

of 270 liters of air. Table VII is an extract from this data and shows the number of milligrams of each smoke component produced by the combustion of 1 gram of materials.

Table VIII shows short-term exposure limits for a number of substances which may be expected to occur in hazardous amounts in smoke. It specifies the highest concentrations which a person may safely inhale for short periods. It must be emphasized that these are not precise figures; but while exposure times of 10 minutes to 1 hour are listed, they should be considered as concentrations which should not be exceeded. Inhalation of greater concentrations is apt to cause a variety of toxic injuries. While some of the figures appear conservative, it must be remembered that carbon dioxide, fear, and activity will increase the respiration rate, thus increasing the dose absorbed by the body in a given time. In addition, it is probable that, when materials are absorbed as particles, they can exert a very much greater effect than when they are inhaled as gas or vapor.

Obviously, the weight of material which can be burned in a confined area will be limited by various toxic products depending on the material. Table IX lists type and amount of material that can be safely burned in 1 cubic meter of space, as well as the number of grams required to reach limiting concentrations.

As can be seen, the most common smoke constituent to create a toxic hazard is carbon monoxide.

Protection against smoke hazards may take various forms. An obvious possibility is selection of materials to minimize the amount of smoke which may be produced. A substantial number of materials produce no visible smoke when heated to 400° F. In this connection, it must be recalled that smoke is not only a product of combustion, but is also a result of pyrolysis or decomposition by heat alone. During actual combustion, some materials burn with very little or no visible smoke, whereas others produce copious amounts of very dense smokes. It is clear then that careful selection of materials can reduce or eliminate visible smoke.

Another method for reducing smoke hazard is through the use of nonflammable covers or coatings. While this principle has been in use for some time (seat upholstery for example), there is an aspect of this practice which requires a word of caution. The products from combustion of certain halogenated epoxy resins, which might be used as fire-resistant materials, can produce a critical amount of halogen acid from very small concentrations. Their extremely irritant quality warns of their presence; however, that may allow corrective action. Table IX lists critical weights and smoke constituents for a range of materials.

TABLE VII. CONTAMINANTS PRODUCED BY COMBUSTION

(Milligrams of contaminant produced by the combustion of 1 gram of material)

	Carbon Dioxide CO_2	Carbon Monoxide CO	Hydrochloric Acid HCL	Sulfur Dioxide SO_2	Benzene C_6H_6	Unsat. Hydro-carbons*	Nitrogen Dioxide NO_2	Hydrocyanic Acid HCN	Chlorine CL_2	Arsine AsH_3	Phosgene $COCL_2$
Acrylic	.63.82	26.04									
Latex Foam	553.50	56.33	0.49	0.006	3.92	0.44					
Leather	247.50	3.53		0.006			0.04	0.005	0.045		
Mineral Wool	340.2	46.37					0.10				
Modacrylic	46.62	26.69	1.38	0.001		63.05		2.52			
Polyurethane Foam	445.5	15.45				9.59					
Plywood	246.63	42.15				5.92				1.3	
Simulated Leather	75.82	33.94				11.29					0.05
Vinyl Foam	116.6	29.37		6.46		0.72					
[illegible]	90	2.86		0.013							

*Determined as acetylene

TABLE VIII. SHORT-TERM EXPOSURE LIMITS FOR SMOKE CONSTITUENTS

Constituent		Parts Per Million (ppm)	mg/m^3	Remarks
Arsine	(A_sH_3)	30	96	6 to 30 ppm can be inhaled for 1 hour without serious consequences.
Benzene	(C_6H_6)	3,000	9,570	3,000 to 4,700 ppm can be inhaled for 1 hour without serious consequences.
Bromine	(Br_2)	4	26	Maximum allowable conc for 30 to 60 min.
Carbon dioxide	(CO_2)	50,000	90,000	Navy permits 1-hour emergency exposure to this level. 50,000 ppm provides signs of intoxication on 30 min exposure.
Carbon monoxide	(CO)	1,500	1,717	NRC emergency exposure limit for 10 min.
Chlorine	(CL_2)	4	12	Maximum allowable concentration for 30 to 60 min.
Fluorine	(F_2)	3	5	NRC emergency exposure limit for 10 min.
Hydrobromic acid	(BRr)	30	99	By analogy to HCL and CL_2.
Hydrochloric acid	(HCL)	30	45	NRC emergency exposure limit for 10 min.
Hydrocyanic acid	(HCN)	60	66	50 to 60 ppm for 1 hour has no serious consequences. 45 to 54 ppm for 30 to 60 minutes has no immediate or late effects.
Hydrofluoric acid	(HF)	20	16	NRC emergency exposure limit for 10 min.
Nitrogen dioxide	(NO_2)	30	56	NRC emergency exposure limit for 10 min.
Phosgene	($COCL_2$)	3.0	12	3.1 ppm is least amount causing immediate throat irritation; 4.0 causes immediate irritation of the eyes; 4.8 causes coughing; 25 ppm is dangerous for even short exposures.
Sulfur dioxide	(SO_2)	30	79	NRC emergency exposure limit for 10 min.

TABLE IX. CRITICAL WEIGHTS AND SMOKE CONSTITUENTS

Material	Weight to Produce Critical Limit (grams)	Smoke Constituent Producing Critical Limit
Acrylic	66	Carbon monoxide
Latex Foam	30	Carbon monoxide
Leather	267	Chlorine
Mineral Wool	37	Carbon monoxide
Modacrylic	26	Hydrogen cyanide
Polyurethane Foam	111	Carbon monoxide
Plywood	41	Carbon monoxide
Insulated Leather	51	Carbon monoxide
Vinyl Foam	58	Carbon monoxide
Wool	600	Carbon monoxide
DER*331 + CA**	0.2	Hydrobromic acid
DER 542 + MDA**	0.3	Hydrobromic acid
DER 542 + MNA**	0.6	Hydrochloric acid
DER X-3448 + MDA**	0.2	Hydrochloric acid
DER X-3448 + MNA**	0.6	Hydrochloric acid

*Dow epoxy resin

**Curing agent

A careful and stringent selection of materials used in the crew and passenger compartment can result in a low fire frequency potential that does not require extensive protective provisions.

Materials should be selected that will not support combustion and that, when ignited, will not continue to burn when the heat source is removed.

Materials should be selected that will not produce toxic products of combustion in quantities greater than can be readily removed by the environmental control systems.

Flame-resistant coatings should be considered for combustible items such as Velcro. The success of tetrafluoroethylene coatings has stimulated the development of coatings, e.g.,"Fairprene," that are capable of resistance to 1,000° C flame environments with no degradation or flame propagation.

The use of nitrogen from inflatable equipment sources should be considered for the crew compartment fire extinguishant.

Manifolding of stored nitrogen should be considered to provide stream, cone, deluge, or high/low pressure saturation of crew and passenger compartments and exit areas.

NASA has extensive findings on odor, carbon monoxide, total organics, and flashpoint factors of plastic materials. This data can be highly useful for design information.

Analyses should be conducted for the following fire safety considerations:

- Sources of ignition hazards
- Determination of equipment capable of explosion or implosion
- Classification of equipment capable of explosion or implosion
- Determination and classification of equipment capable of temperature hazards

The handling and use of flammable liquids must be carefully controlled to prevent fires and explosions. The basic measures commonly used are:

- Prevention of evaporation by keeping flammable liquids in closed containers
- Removal of sources of ignition

- Adequate ventilation

- Use of an inerting atmosphere of gas instead of air

- Provision of relief vents to minimize structural failure and danger from explosions

- The installation of fixed automatic and manual fire extinguishing systems

Chemical fire hazards often are not readily recognized. Apparently harmless chemicals may react vigorously, causing fire or explosion, upon contact with commonplace substances. Some chemicals, when contacted by other materials, will generate heat, give off flammable gasses, or react explosively. Others through decomposition, may generate heat and ignite spontaneously or support combustion by oxidation. It is important to remember that chemicals may not be flammable in themselves, but can cause fire under certain circumstances.

Liquid and gaseous oxygen is not flammable itself, but will support rapid combustion of most other materials. The contamination of any flammable materials by oxygen is extremely dangerous, especially materials such as oil, paint, and grease.

The selection of an extinguishing or suppressing system involves a number of considerations. The primary consideration is effectiveness.[47] The designer must select the agent and technique that will accomplish the intent during the worst possible conditions, in the minimum time, and with minimum damage to equipment and systems. Toxicity to personnel can be rated second in importance to effectiveness when exposure to hazardous concentrations is unlikely or when escape from the vapors is possible. Effect of the agent on equipment is important. Extinguishing the fire is of little help if some piece of flight- or mission-essential equipment is damaged beyond use by the extinguishing agent. The most common extinguishing agents are as follows:

- Carbon dioxide (CO_2)

- Bromochloromethane (CH_2BrCl)

- Dibromodifluoromethane (CF_2Br_2)

- Bromotrifluoromethane (CF_3Br)

- 1,2 dibromotetrafluoroethane (CF_2BrCf_2Br)
- Carbon tetrachloride (CCl_4)

Explosion suppression systems consist of extremely sensitive pressure or flame detectors that sense an impending explosion and discharge an inhibiting agent. The agent suppresses the explosion before the pressure can reach a dangerous level.

A limiting factor in use of high expansion foams and chemicals is the requirement for pure air to complete chemical reactions and foam expansion. Tests have indicated insufficient foam generation where combined with smoke-laden air. Design of any aircraft high expansion foam system will have to seriously consider this limiting factor.

It is to be noted that all fire suppressants identified will require analysis and testing with respect to the extinguishants toxicity levels and toxicities of their pyrolysis products.

4.4.3.5 Controls or Displays: Instruments and equipment should be provided that will prevent or minimize the generation of hazardous spallation due to penetration by projectiles or fragments; for example, nonsplintering or nonshattering instrument face glass to prevent or minimize crew injury.

The controls and displays should be designed to be free of sharp objects that can cause crew injury. All protrusions should be padded.

Electrical systems should be designed to minimize electrical shock of aircrew due to projectile damage.

Displays and malfunction warning systems should be designed to give the aircrew members sufficient information to determine the location of major malfunctions and take corrective action.

Delicate components should be located where the probability of a hit will be minimized and where they will be protected from secondary weapon effects.

Controls, such as switches and adjustment screws, should not be located close to dangerous voltages.

Hand-grasp limitations that may be imposed by wounding of the aircrew should be considered.

4.4.3.5.1 Special Problems: Means should be provided to prevent or minimize explosive decompression or loss of essential aircrew stations or equipment pressurization by ballistic damage.

Automatic warning and necessary corrective actuation of essential aircrew station equipment damaged by small-arms weapon effects should be provided where sufficient time would not be available for aircrew assessment and application of such corrective measures.

Breathing oxygen supplies should be placed outside of crew compartments where its damage from weapon effects would cause aircrew injury, inability to complete the mission, or abandonment of the aircraft. A fire- and fragment-resistant barrier should be provided between the aircrew station and oxygen supply compartment to prevent or minimize aircrew injury from an exploding oxygen bottle or converter.

Separate or redundant oxygen supplies should be used for multiple pilots or aircrew members where loss would result in mission degradation of personnel incapacitation. Refer to MIL-D-19326 for illustration of multiple oxygen supply system circuits.

4.4.3.6 Cockpit/Cabin Armor: The achievement of acceptable armor protection confronts the designer with severe problems of comfort, cockpit space limitations, and weight. In addition, armor is of no value unless aircrews use it as intended.

It is not reasonable within the present state of the art to provide full armor protection against small-arms fire within the confines of the cockpit. Such a requirement unduly compromises the efficiency of the crew and indirectly increases their vulnerability to larger weapons. Full protection may become feasible in the future if armor can be used in conjunction with devices such as gunfire detectors and periscopic gun sights. Protection should be provided against multiple hits striking more than one area and more than 6 inches apart. The trunk/torso area of the pilot and copilot should be protected against small-arms fire striking from positions below a horizontal plane that passes across their shoulders, while the aircraft is in a level-flight altitude and the men are seated in a normal manner. Although it is difficult to provide head protection, it is desirable to consider this area to be protected also. Some protection from the rear and sides of the head may be possible. When considering this area, the horizontal plane should be moved to pass across the top of the aircrewmember's head.

Where personnel protective armor is required, use the seven-step procedure shown in Table X for design of passive defense installations. Detailed information on the seven-step procedure is contained in Reference 12.

TABLE X. SEVEN STEPS FOR DESIGN OF PERSONNEL PROTECTIVE DEFENSE AGAINST BALLISTIC THREATS

1. Lay out detailed aircraft configuration showing location of personnel and major items of equipment and structure.

2. Lay out zones of most likely threat aspects on configuration drawing.

3. Determine natural shielding from equipment and structures. Use this information to select armor material type and ballistic resistance that together will defeat the threat. Modify size and location of panels to minimize penalties.

4. Position armor panels to cover zones established in Step 2. Panel placement will depend upon available space permitted by configuration.

5. To confirm or reject material selection and panel locations, consider the following design details:

   a. Effects on system weight and center of gravity (CG).

   b. Effect on system operations if armor must be added to escape systems.

   c. Exact space available and limitations or penalties for maintenance actions.

   d. Human factors, such as crew visibility, ability to control the aircraft, mission duties, restriction to movement, fatigue tolerances, and escape capabilities.

   e. Installation penalty factors.

6. Analyze loads and stresses of panels and their attachments for detail design.

7. Conduct final weight and CG analysis.

Protective equipment shall not restrict or interfere with the movements of the crew that are required for normal operation of the aircraft. In addition, the protective equipment:

- Shall not interfere with normal aircraft operations.
- Shall not restrict the critical portions of the external field of vision of the crew.
- Shall not impair depth perception.
- Shall not impair color perception.
- Shall not degrade visual acuity.
- Shall include features to permit rapid egress from the aircraft in emergency situations.
- Shall be fire retardant/resistant.
- Shall present no projections or cutting edges in case of failure due to loads in excess of the crashworthiness design values.
- Shall be interchangeable and not custom-fitted for each aircraft. If modular design is used for two threat levels (e.g., caliber .30 and caliber .50), the modules should have common mounting provisions.
- Shall not be a source of secondary hazards such as spall.

The use of armor material as basic aircraft structure for the transmission of crash impact loads is considered both feasible and practical. Refer to Reference 38 for converage of this subject.

Measures of protective characteristics of armor materials are many and varied, as follows:

- The depth of penetration into a section that is thick enough to prevent complete perforation
- The number of layers required to stop the projectile
- The projectile velocity required for a specified probability that penetration will occur; or more generally, the probability of penetration as a function of projectile velocity

- The velocity of the projectile after it has passed completely through the armor

- The minimum angle of obliquity at which the projectile will be defeated

These measures can be expressed in terms such as the "safe" minimum distance from a specific small-arms weapon, the probability that a hit will kill, the probability of survival, the percentage of increase in survivors, and the reduction of casualties.

The following factors must be evaluated when considering the installation and placement of armor within the cockpit:

- Added weight
- Area coverage
- Restriction of vision
- Restriction of movement
- Comfort
- Controls accessibility
- Structural degradation
- Ballistic effectiveness
- Overall center of gravity
- Crashworthiness and crash survivability

The following additional factors are desirable when considering the installation and placement of armor within the cockpit:

- Protection for the head and neck
- Frontal protection
- Shatter- and crack-resistant window and canopy materials

Transparent armor for use in visors, viewports, helicopter bubbles, etc., pose special problems and restrictions. Some glasses have general potential applicability for armor.

A suitable shield should be incorporated when armor material is a type that may spall on its front face and endanger the protected or adjacent crewmen. Suitable provisions should be made to suppress spall and prevent injury to crewmen when armor materials are used that generate spall particles from the rear face when defeated.

Adding armor to a door can make it heavy enough to permit damage to the aircraft if the aircrew allows it to swing against the structure when entering or exiting. A strong door stop should be incorporated in the design to hold the door when it is swung open. It is also advisable to include a damper or snubber to prevent the door from being slammed open or closed. The energy absorber, to be efficient, must generate a constant force that is uniform throughout the entire stroke and is independent of velocity. The installed device should not lose its efficiency or require maintenance under typical helicopter operating environments.

4.4.3.7 Seats: Occupant protection and survival should be a primary consideration in the design, development, and testing of aircrew seats. This requirement must be approached from two aspects: the effects of small-arms fire and the crashworthiness in an aircraft accident. Specification MIL-S-58095 (AV) gives detailed information on armored or unarmored crashworthy aircrew seats.

Reference 33 states that "adequate occupant protection requires that the seat be retained generally in its original position within the aircraft throughout any survivable accident." In addition, the seat should in some cases provide an integral means of deceleration attenuation. Use Reference 39 for detailed information on crashworthy seats, including restraint systems. The following paragraphs describe the protection of the seat occupant against small-arms fire.

The designer must continually consider functional effectiveness, cost, and ease of maintenance. Protection designed into the seat will defeat its own purpose if it is not used as intended, is discarded by the occupant, is difficult to maintain, or costs too much to produce or to replace.

Achievement of acceptable armor confronts the designer with severe problems of comfort, cockpit space limitations, and weight penalties. Thus, the designer must coordinate his seat armor development effort with the requirements and criteria for cockpit/cabin armor. Special problems are created by the configuration and controls of the helicopter and by specialized survival and flight equipment. Some of the problems must be worked out empirically with the aid of mockups and experienced aircrew members. The

ideal situation of enveloping the pilot/copilot in armor must be compromised in favor of (1) the pilot's controls, and (2) the necessary clearance for the operation of the pilot's controls, and (3) the clearance for ingress to and egress from the aircraft.

Armor applied to the seat should supplement other protective devices and techniques and should protect the trunk-torso body area of the occupant when seated in the normal manner. This protection should defeat small-arms fire striking from positions below a horizontal plane passing across the man's shoulders while the aircraft is in level flight altitude. This protective equipment should not restrict or interfere with the normal operation of the aircraft by the crew.

The seat protective unit should not interfere with the proper operation of the occupant's safety restraint under either routine or emergency flight conditions. The unit must be well secured to the aircraft structure, must not entangle the man with projections, and must permit rapid exit from the aircraft. Sharp corners, edges, and projections must be rounded and padded. Straps, laces, and buckles must be secured to prevent flapping, especially near open doors and hatches. The seat unit must not swivel uncontrollably and must permit the occupant to steer it by means of foot and leg pressure against the floor of the aircraft. The sitting surface and the crotch protector must have sufficient padding to prevent damaging effects from turbulence and vibration. The crotch protection unit must deflect away from the man when it is struck sharply. See Figures 50 through 54 for representative seat assemblies that have been developed and evaluated.

Reference 39 describes an experimental seat assembly. The seat bucket is constructed of ceramic armor and provides ballistic protection for the 95th percentile crewman from fire from the side, bottom, and back, from midthigh to shoulder height. Armor coverage totals 13 square feet. The restraint system consists of a lap belt, single point attachment-release buckle, shoulder harness, and center tiedown strap. These are all secured to the seat bucket, to insure occupant restraint during seat bucket movement; e.g., when the seat energy absorber strokes. The seat bucket is attached to the seat support structure in such a manner that the bucket will stroke vertically a minimum of 12 inches while limiting occupant deceleration loading to human tolerance levels. This assembly requires adequate strengthening of the floor.

Armored pilot and copilot seats have been designed and produced for the CH-54 aircraft. They provide .30 caliber armor-piercing (AP) level of protection and are interchangeable with unarmored seats. They are composed of a basic continuous-wall seat bucket made from boron carbide material with a fiber glass laminate backup. Armored side panels, constructed from the same materials, are fastened to the seat by hinged attachments

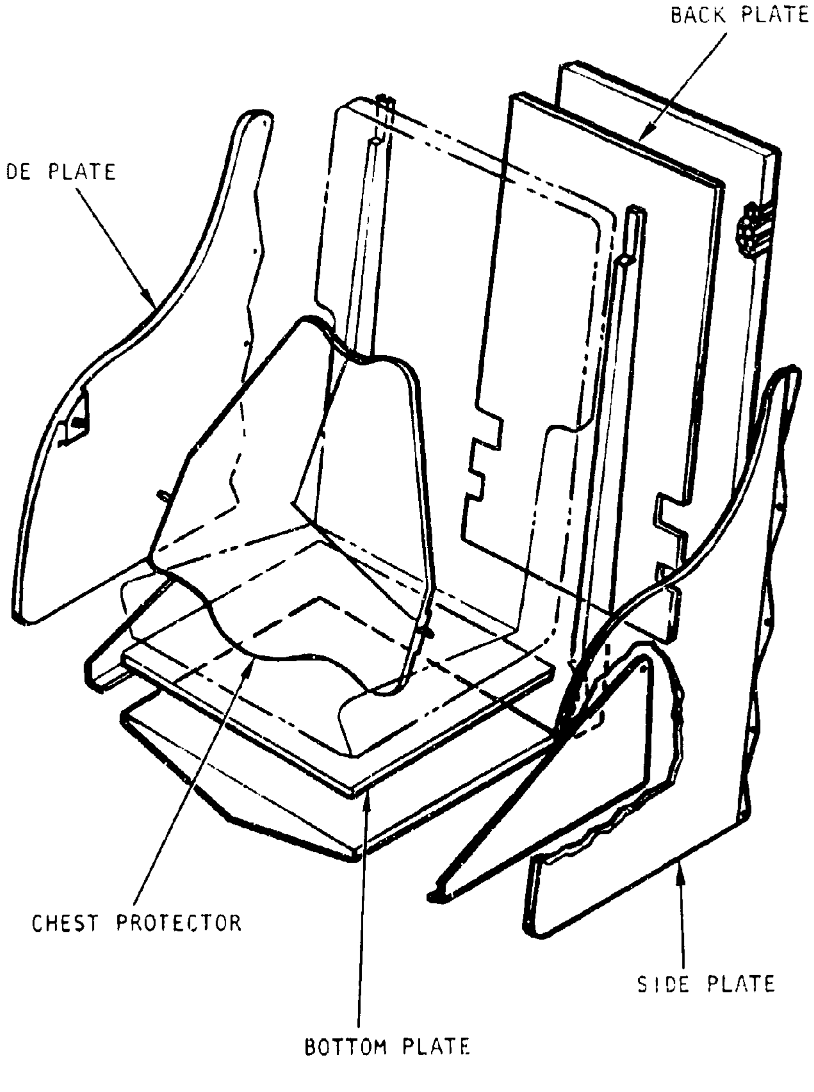


Figure 50. Isometric of Armor System.

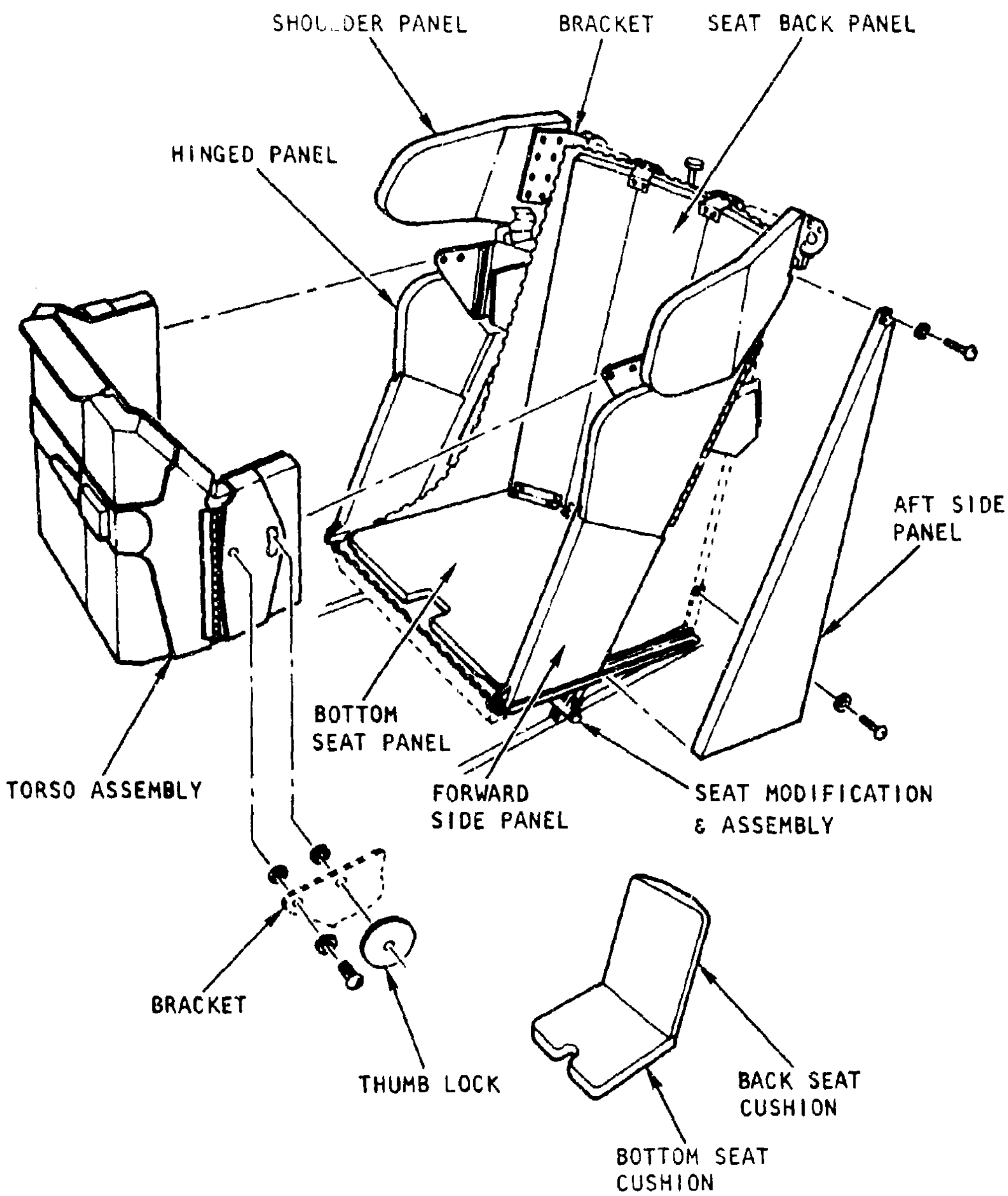


Figure 51. UH-1 Modular Armor System.

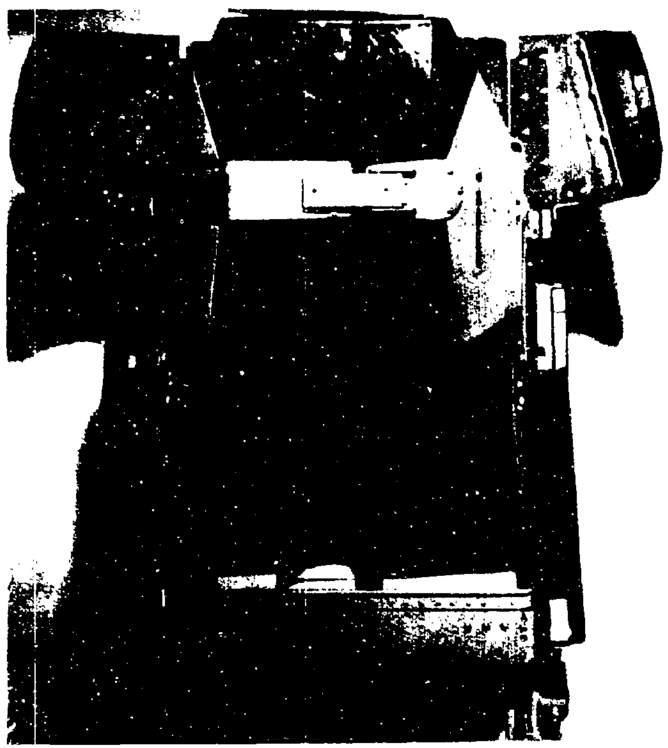


Figure 52. Armor Seat-Closed Position.

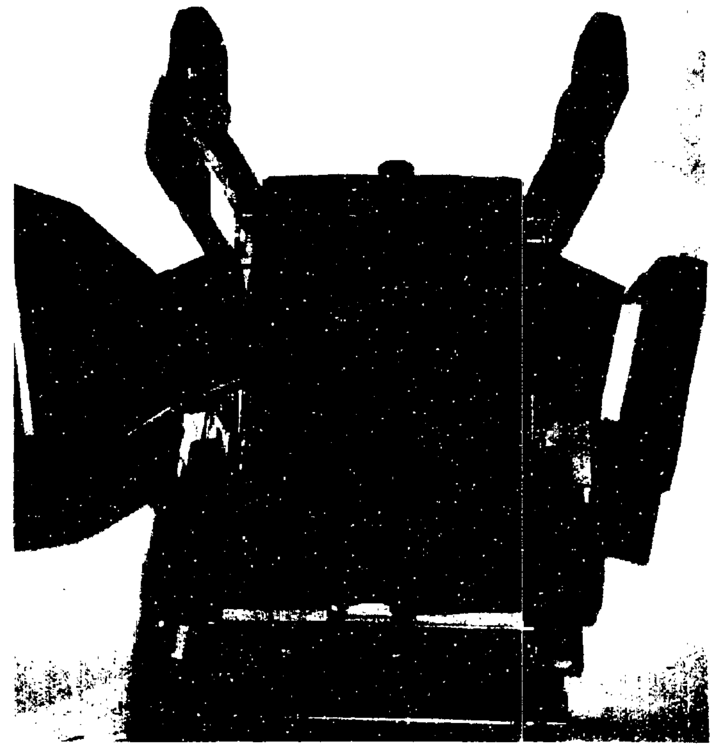


Figure 53. Armor Seat-Open Position.

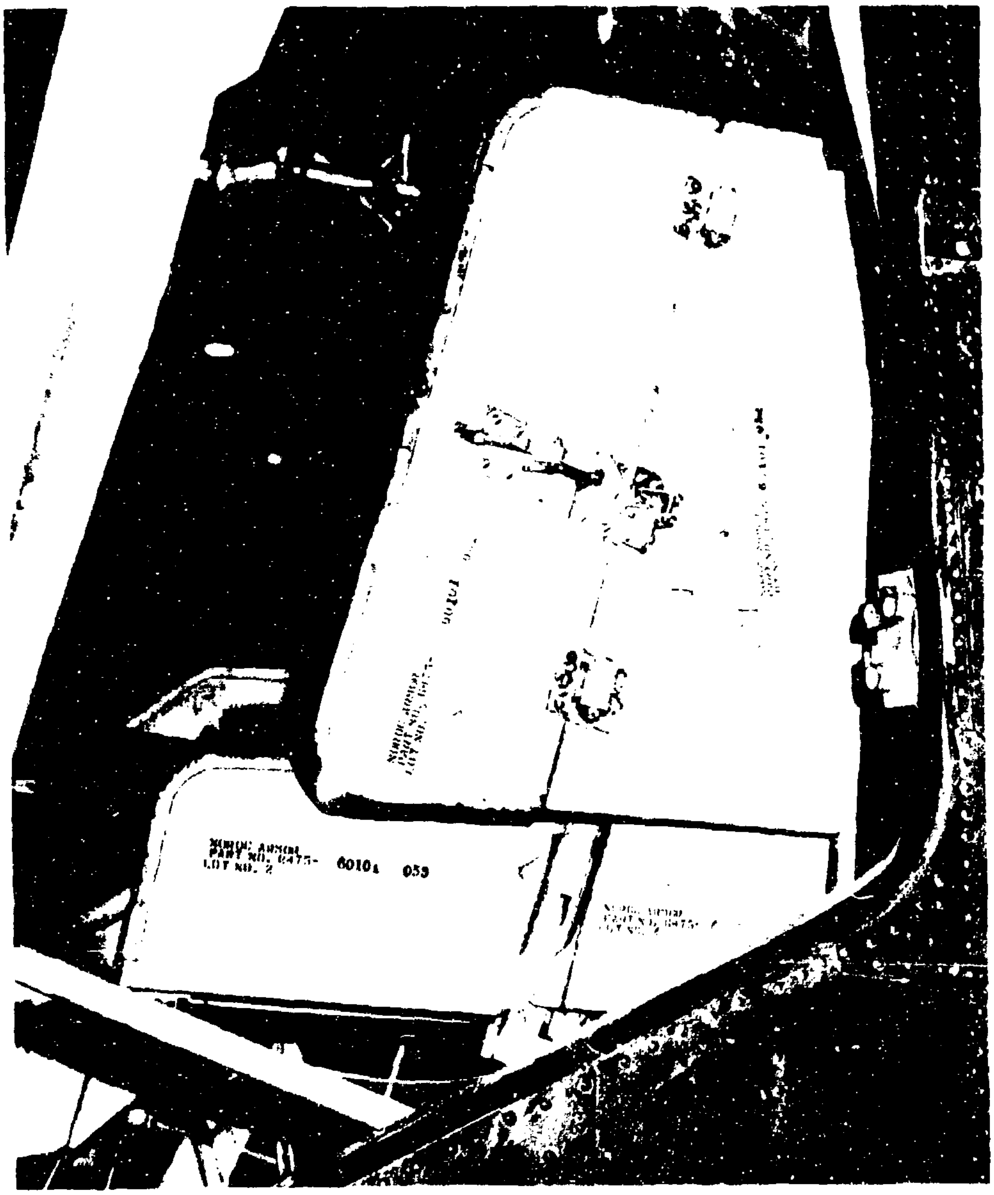


Figure 54. Articulated Armor Seat Installation.

that permits easy ingress to and exit from the cockpit. Figure 55 shows a view of the seat assembly complete with cushions and restraint system. Figure 56 shows a view of a pilot in the seat with one side panel folded back. Figure 57 shows the seat installed in the aircraft.

A chest protector provides front armor. This is supported on the seat bucket by pivoted arms to allow the necessary pilot movement and to permit the armor to swing forward away from the pilot's chin in case of a crash. The chest protector is readily removable and may be stowed elsewhere in the helicopter when desired.

Other experimental seat programs have established the following design concepts and criteria for seats and seat protection:

- If ceramic armor is used, it may be divided into small sections 3, 4, or 6 inches square, to protect against multiple hits. A hit on one section should not destroy or crack another section.

- An armored torso shield installation must not interfere with the operation of the pilots' controls.

- A design that uses the armor panels as structural elements of the seat should be considered.

- Side armor panels, shoulder panels, and torso shield armor should be easily removed for replacement.

- Armor considerations must be approached differently for tandem seats versus side-by-side seats.

- If a modular armor design is used as kits, consideration should be given to design against two threat levels, e.g., caliber .30 and caliber .50. They should be interchangeable in order to use the same mounting provisions.

- Dual use has been made of armor material as a load-bearing structure in a seat design, and it appears to be feasible for operational use.

Headrest armor must not interfere with head movements or block the vision of crewmen. Current headrest armor is not being used as intended because of these factors.

Seat armor must be designed to prevent interference with performance of the crewman's primary mission. For example, the design of a protective seat

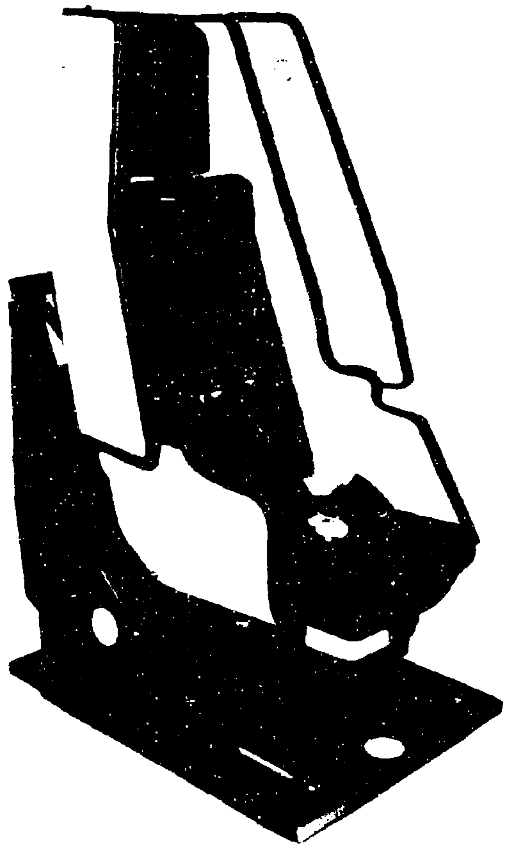


Figure 55. CH-54 Boron Carbide Armor Seat Assembly.

Figure 56. CH-54 Boron Carbide Armor Seat With Hinged Panel Folded Back.

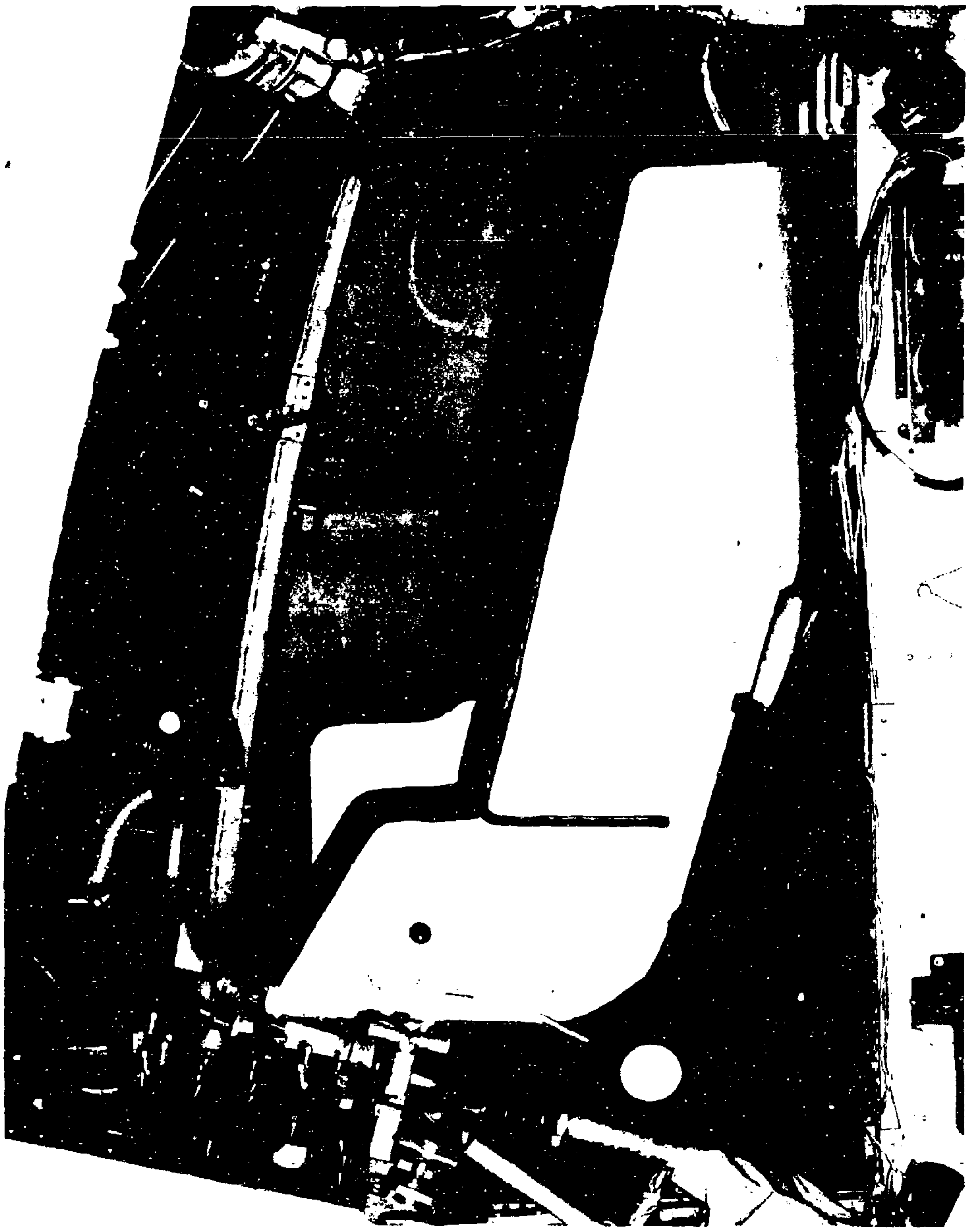


Figure 57. CH-54 Boron Carbide Armor Seat Assembly Installed in Cockpit.

for a door gunner must permit the necessary body movements that will allow him to fire his weapon straight down, forward, laterally, and aft.

Protective seats must be designed to minimize fatigue and to prevent safety hazards.

- Compatibility must be provided between the protective seat unit and the clothing and other equipment worn by the occupant.

- Fatigue can be reduced by providing a well-balanced seat unit that is shaped and located to permit a stable but relaxed body position for effective operation of flight controls, weapons, and other equipment handled by the crew.

A protective seat unit should accommodate all aircrewmen (5 to 95 percentile) while wearing the necessary complete combat equipment, including torso and leg armor, sidearms, canteens, and survival kits.

A protective seat assembly that includes a crotch protector should have a positive stop to prevent the crotch shield from moving to the rear in case of a projectile hit.

Reference 40 provides a detailed evaluation of seat/groin protective units that address the following considerations:

- Description of item and concept of use
- Adequacy of seat/groin unit dimensions
- Estimates of length of time the seat/groin unit can be used
- Comments
- Best-liked features
- Conclusions concerning the seat/groin protective unit.

Reference 41 provides human factor requirements and recommendations for protective seat assemblies, including:

- Dimensions
- Contours
- Edge finishes

- Seat cushions
- Cover materials
- Location of seat units and supporting structures
- Clearance from surrounding structures.

The helicopter pilot's seat assembly requires a special space allowance for operating the collective stick. Clearance for the pilot's hand on the stick is a factor that limits the allowable seat width. Arm clearance is a factor in determining the shoulder armor location and the seat support configuration.

The design of a torso shield should include the following considerations:

- Depth must be provided to clear the chest of a 95 percentile crewman.
- The underarm height must be nonrestrictive to the 25 percentile crewman.
- The shield must be easily detachable for ingress and egress.
- The shield must be fully supported by the seat.
- The shield must be connected to the seat until physically released. Crash loads shall not dislodge it and turn it into a missile.
- The shield should have a single-point release mechanism.
- The occupant must be able to reach a forward or overhead instrument/control panel without disconnecting the structural support.
- The occupant must not be guillotined or have his face crushed if crash loads snap his head forward upon the shield. A barrel-shaped shield, breakaway shear pins, or an automatic seat-mounted inertial reel and strap at the top of the seat back to restrain the occupant should be considered.

To be effective, the energy-absorbing stroke of the seat must be as long as possible, within practical limits.

Reference 11 contains information on the different applications of plastic-ceramic composite armor on seats of current Army aircraft and helicopters.

Reference 42 presents a detailed description of the design, associated testing, and analyses that were conducted in developing the improved UH-1 aircrew modular armor system design. The primary objective of this design was to provide increased ballistic protection against the caliber .50 AP M2 (armor-piercing, 100-yard velocity, impacting at a 15-degree obliquity). In addition, an identically designed system was developed for the caliber .30 AP M2 or 7.62 mm M61 threat level. Both systems are designed to permit interchangeability of panel components from either system without changing common mounting bracketry.

This improved modular armor design, while providing a maximum of protection, does not interfere with the flight operation requirements of the pilot or copilot.

This improved modular armor design concept will permit flight-line personnel to quickly change the armor to counter the changing threat level encountered in the combat area. When the caliber .30 AP M2 or 7.62 mm M61 threat level is present, the interchangeability concept permits use of the light armor or removal of all armor, thereby making available additional mission payload.

4.4.3.8 Body Armor: All aircrewmen operating in aircraft subject to small arms-fire require protection. Body armor is one form of such protection that should be considered. Since it is Government-Furnished personnel equipment, the design criteria, data, and problems presented are included in this guide to increase understanding and enhance integration with the airframe and equipment design.

Personnel armor for pilots and copilots presently consists of front and back torso shields, although the back shield is not worn if the seat back is armored. Door gunners may also wear this armor. Figures 58 through 62 show a variety of representative body armor assemblies.

Any projectile can be defeated by an adequate thickness of armor material. But the adequate thickness, in most cases, materially increases the weight that must be carried by the aircrewman, which makes it harder for him to move about and causes him to tire rapidly. In addition, for threats greater than caliber .30, while the threat can be defeated, the transfer of projectile impact energy through the body armor to the body could be fatal to an aircrewman wearing the armor. Thus, reduction in weight

Figure 58. Aircrewman Wraparound Body Armor - Front View.

Figure 59. Aircrewman Wraparound Body Armor - Back View.

Figure 60. Aircrewman Upper Torso Body Armor.

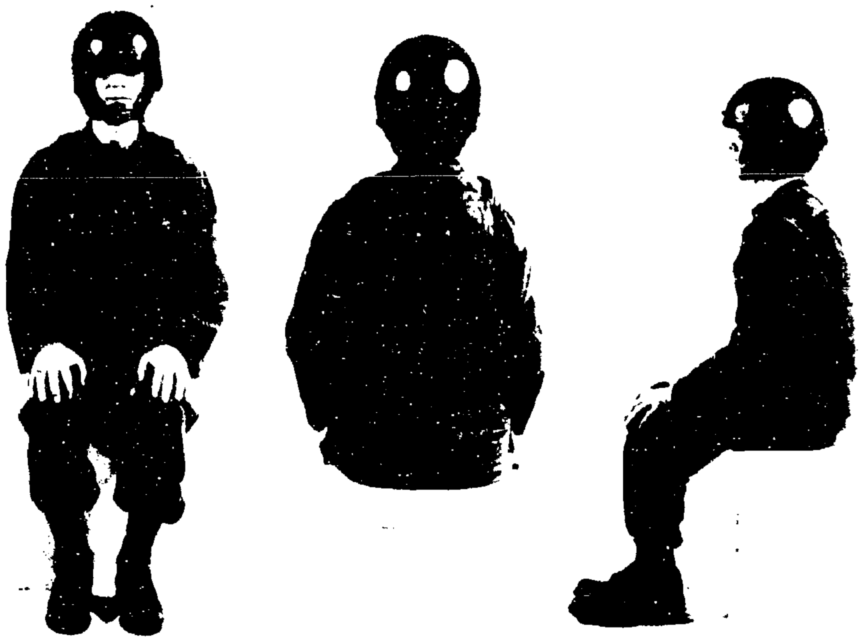


Figure 61. Aircrewman Upper Torso Body Armor - Seated.

Figure 62. Lightweight Formed Body Armor - Ground Personnel.

without corresponding loss in protection, as well as effectiveness of body armor to the wearer, is the driving force behind all armor development programs.

A discussion of armor concepts and armor materials is included in Chapter 3 of this design guide. Only specific body armor details will be addressed herein. Reference 46 provides additional detailed data on human factors in the design of personnel armor.

First-hand observation is the only way to accurately determine the extremes of movement of the average aircrewman during a normal mission. Therefore, it is important to have the designer as close to the user as possible so that there is a clear understanding of the manner in which the armor will be used. The aircrew member is a human being with psychological and physiological demands, and the designer must be sensitive to his needs. The aircrewman will not tolerate a protection system if it inhibits his ability to do his job. He must be provided an item that is functional; one that will permit him to do his job without unreasonably taxing his endurance; and one that protects him from the danger of projectiles, fragments, shrapnel, Plexiglas, and metal debris.

The task of measuring the human body and its changes in shape and dimensions during movement can be a major challenge when designing body armor. The following special techniques are discussed in Reference 11:

- The distortion-grid method is valuable in determining the outer limits of the armor contour, to determine how far to extend the armor before interference occurs.

- The composite contour method provides contour information which can be used to design an effective armor shape.

- The vertical contour envelope (standing) is a precise contour envelope depicted graphically.

- The vertical contour envelope (bending forward) emphasizes change of contours, especially in the chest profile.

- The horizontal contour envelope is applied to the horizontal profiles.

- The leg contour envelope emphasizes the unsymmetrical contours of the leg.

- The composite contour envelope represents the maximum and minimum contours of all subjects measured. This makes it possible to fashion armor in various sizes and to fit the armor within the boundaries. It provides relative assurance that the armor shape will not interfere with the body surfaces. It enables the designer to avoid pressure points from the rigid elements on the armor that are in contact with the body.

A sizing system that offers two armor widths for each of two armor lengths is extremely versatile for torso armor. The critical dimensions in sizing rigid torso armor are chest breadth and torso length. The breadth of the armor is particularly critical: it will cause immediate interference at the sides if it is too narrow; if too wide, the free space and loose fit may cause unexpected problems.

Back torso armor usually covers a substantial area of the upper body. The more area coverage that is provided, especially at the sides (often called wraparound), the more critical is the breadth of the armor, since the body is virtually encased by the rigid elements and they must match the body dimensions reasonably well.

The method of suspending and coupling the load of armor to the body is a challenge from a design standpoint. A brief description of several typical suspension systems follows this paragraph. The designer should attempt to develop improvements wherever possible.

The cantilevered web system uses rachel net over the shoulders, continuing down to about waist level. The rachel net conforms quite well to the shape of the body, and distributes the load over large areas of the torso. This makes load bearing more comfortable and improves the man's tolerance for the armor. It also offers excellent ventilation and permits a "breathing action" next to the body.

The tension web system integrates the rachel net with the other fabric elements of the suspension system. When the armor is pressed against the body, the rachel net helps to absorb the direct load and distributes it to the fleshy portions of the torso. This form of tensioned surface makes the armor more comfortable and increases the stability of the heavy elements that contact the body.

Experimentation has shown that supporting the armor load is somewhat different than other forms of load-carrying, such as rucksack or backpack. When a heavy front element is added, a whole new set of conditions is introduced. The CG tends to move closer to the centerline of the man, and the load forces are applied more vertically in the shoulder areas.

When endured over an extended period, a concentrated load in the sensitive area of the shoulder can become quite distressing and may cause extreme fatigue and dizziness. This fatigue tends to build up unconsciously and can degrade a man's performance very rapidly after a point in time.

The waist augmentation system transfers a portion of the total armor load to the waist and the hips. A feature of this system is that the wearer has the option of proportioning the total load between the shoulders and waist to the extent that makes him feel most comfortable. If he is relatively immobile for a long time, such as sitting in the aircraft, he may wish to transfer most of the load off of his shoulders. Under other conditions, he may wish to shift most of the load to his shoulders. Another feature of this system is that the waist support element does not encumber the man in any way. It is easily separated from the rest of the armor system, and it requires no permanent attachments. It is essentially of fabric construction with the exception of two narrow stays at the sides to keep the fabric from buckling. This system can be used in combination with the rachel net and web systems.

Ceramic body armor materials that are currently in production include alumina and boron carbide. Both materials when backed with a fiberglass-reinforced plastic will stop 7.62 mm AP projectiles.

Ceramic/GRP (glass-reinforced plastic) composite armor proved itself in the Southeast Asia conflict. This lightweight armor consists of a ceramic face bonded to a deformable backup plate and can defeat 7.62 mm AP projectiles. The armor also provides protection against small-arms fire within tolerable weight limitations. Problems with this type of armor do occur; e.g., the spall fragments expected from composite armors are of such size and velocity that they can wound personnel. One solution to the spallation problem has been to use one ply of ballistic nylon or equivalent spall cover bonded to the armor facing to confine the spall area, decrease the velocity of the fragments, and contribute to better multiple-hit capability.

Another problem with ceramic armor has been cracking and fracturing. This has been solved by dividing it into small sections about 6 inches square. This protects against multiple hits more than 6 inches apart because a hit on one section will not destroy or crack another section. Systems to contain or minimize the hazards of spall have been developed, but none of them has solved the problem at an acceptable weight, under all conditions of attack. See Figure 63 for an expanded view of plastic-ceramic composite armor.

The head of an aircrewman in a crash situation is subject to contact with his personnel armor in two major areas, as shown in Figure 64. These are defined arbitrarily as the face, which extends between 1 and 2 in the figure, and the neck, which extends between 2 and 3. Violent contact of

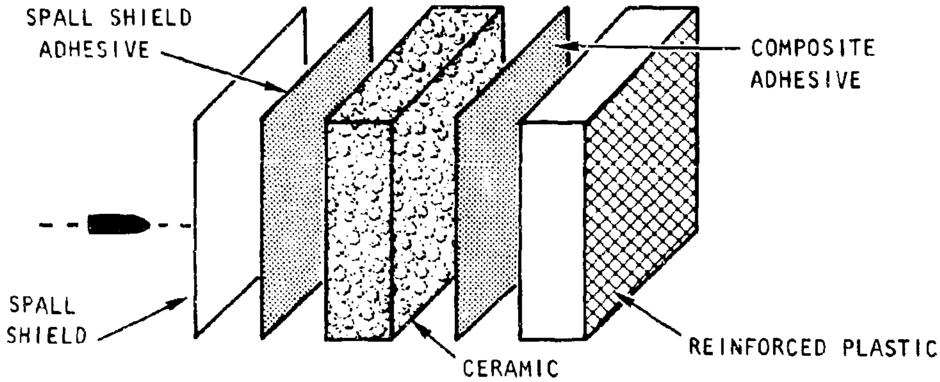


Figure 63. Plastic-Ceramic Composite Armor (Expanded View).

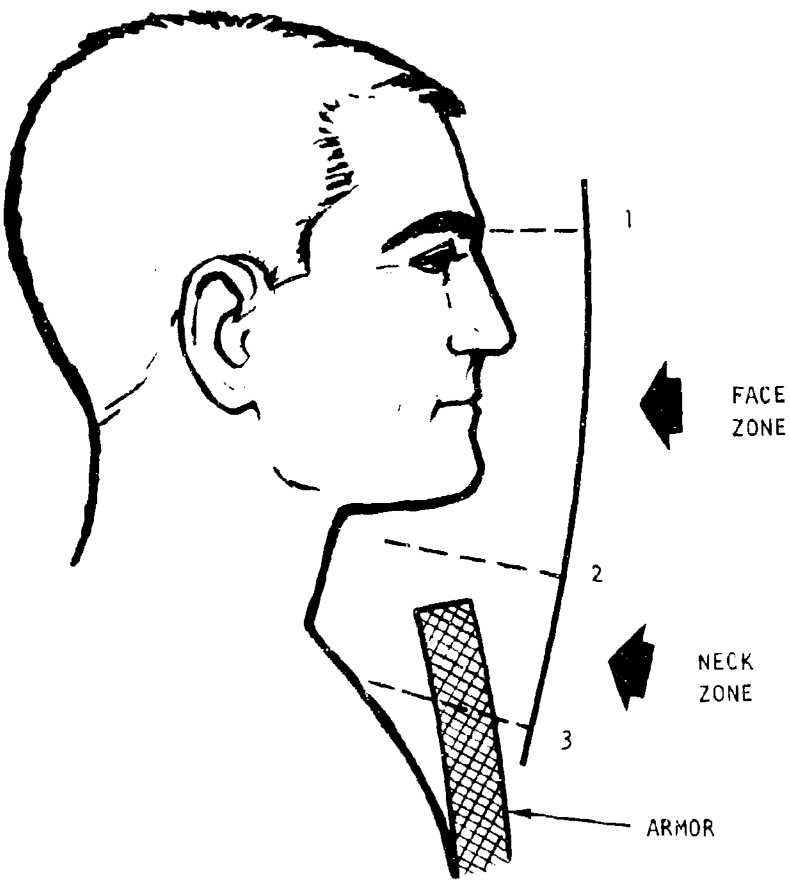


Figure 64. Face/Armor Contact Zones.

the face with the armor can produce head injuries. It is likely, however, that such impact will render the victim unconscious with only minor injuries initially, but leave him vulnerable to subsequent serious or fatal injuries due to postcrash fire, drowning, or hostile action. Contact of the neck with the armor can produce serious damage, even if such contact is not particularly violent. The most dangerous possibility is a fracture of the trachea, especially at the larynx. Such a fracture may easily result in death by asphyxiation due to a vocal cord spasm or collapse of the trachea.

Reference 44 describes the methods and results of an experimental program to determine the force-time relationship resulting from head-neck interaction with three types of aircrew armor, with and without aircrewman helmets. Based on the data collected during this series of tests, it is concluded that:

- Body armor shows a propensity for collision with the face during moderate impact decelerations.
- Peak loads resulting from head/armor contact vary widely.
- The pulse shape is consistently triangular with a time base of from 0.025 second to 0.045 second.
- The addition of a protective helmet tends to increase both the frequency and the severity of head/armor contacts.

Recommendations for solution to the foregoing problems are as follows:

- A padded front collar should be considered for body armor. This will deflect spatter and spall from the exposed throat area and will also attenuate the impact force between the armor and the face during a crash. One version of a collar pad is shown in Figure 65.
- Armored vests should be well-fitted and worn snugly with a tight shoulder harness.
- Emphasis should be placed on the development of suspension and restraint systems for body armor.
- Emphasis should be placed on in-depth injury evaluation of accident experience in Southeast Asia to determine the after-the-fact crashworthiness of the aircrew armor. Equal emphasis should be placed on the study of direct injury and postcrash evacuation.

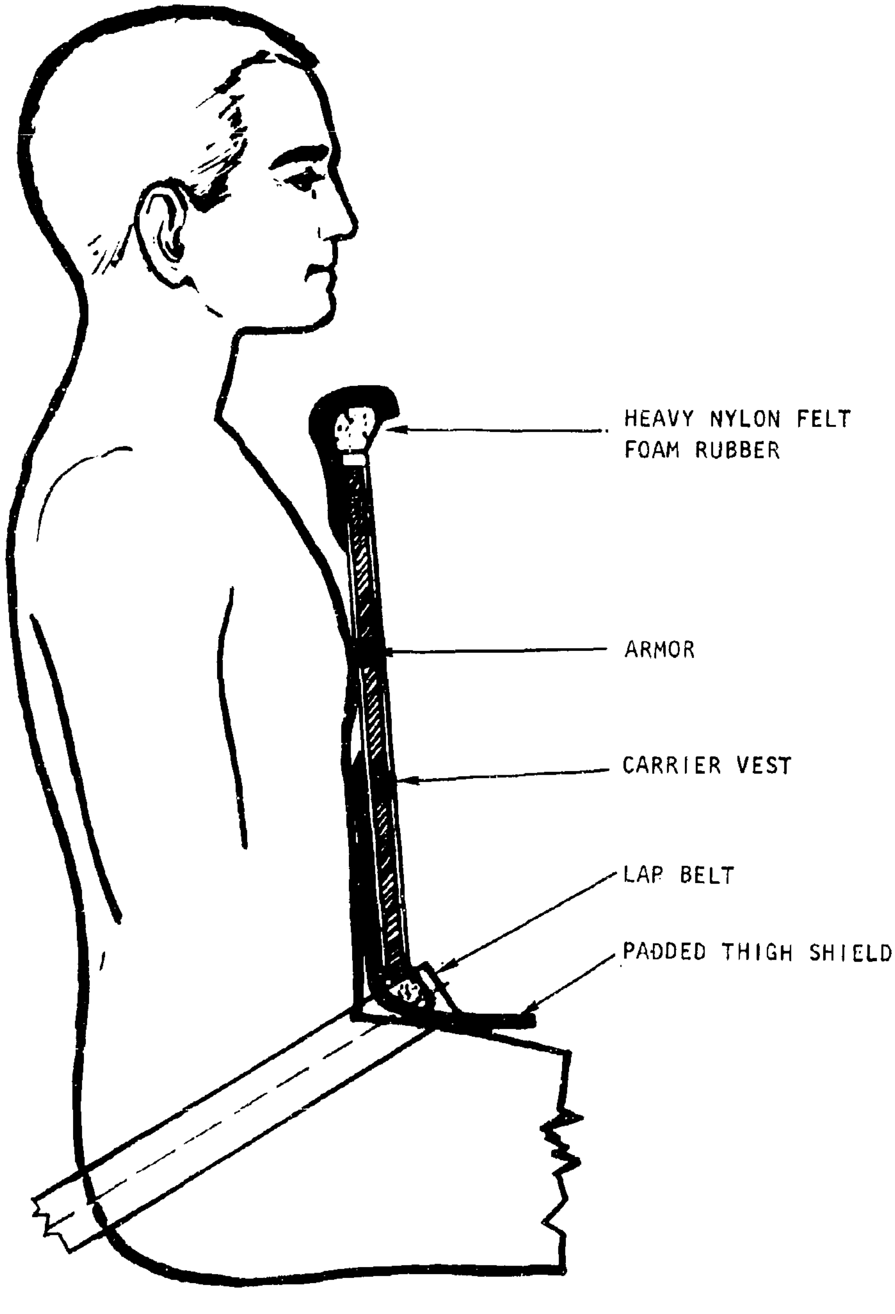


Figure 65. Recommended Padding for Upper and Lower Edge of Armor.

Curved chest armor plate has been developed and tested by industry. The experimental chest armor consisted of a ceramic-covered fiberglass plate molded to partially encase the wearer's chest. The upper edge of the plate was also curved outward away from the wearer's face. Based on the rather limited data collected during the test, it is concluded that:

- Head/armor contact with the curved armor is more severe than with standard armor under the same deceleration conditions. During deceleration, the upper torso and head are free to develop excess velocity with respect to the seat before contacting the armor.

- The point of head/armor contact with the curved armor is more unpredictable and may be a function of the way in which the shoulder harness is worn.

- The curved armor seriously compromises the effectiveness of the restraint system, especially upper torso restraint. The front curve on the armor tends to hold the shoulder harness away from the body.

Some of the problems encountered when using body armor are as follows:

- The weight of the armor contributes to fatigue.

- Heat stress is increased because of the closeness of the impervious armor plate to large, actively sweating areas. This contributes to physical fatigue and irritation.

- Man-machine interference can result because of the increased bulkiness and its incompatibility with seats, parachutes, and flight controls.

- Spalling of the armor plate contributes to secondary injuries, especially in the face and eyes.

- Crash injuries have resulted in detached or loose teeth, bloody noses and lips, broken jaws, and heavy bruises to the upper thighs. The nylon fragmentation vest has been implicated as contributing to the severity of burns in postcrash fires.

The additional weight of body armor is too much for presently available flotation devices to support successfully. If the flotation gear is worn inside the armor, it is difficult to initiate the inflation process, and the space required for inflation is reduced. If worn outside, over the

bulk of the armor, it is susceptible to damage and to hanging up on controls, structure around exits, etc. It can also prevent removal of the armor.

Unique benefits have been provided by body armor in addition to protecting the aircrewmen from hostile weapons. The nylon vest (flak vest) has been found to be a good supplemental flotation aid because of its construction, i.e., multiple layers of nylon encased in a plastic bag. The chest plate is known to have absorbed and spread the impact of collision with controls or instrument panels, to the point that injury was markedly reduced in some crashes.

4.4.3.8.1 Leg Armor: Leg wounds are not a major source of fatalities, although an artery could be hit. Optimum desirable characteristics of leg armor include the following requirements:

- It must provide maximum, reasonable protection against small-arms fire and related fragments.
- It must not be a source of secondary weapon effects, e.g., spallation and spatter.
- It must be integrated into or be compatible with other survival and flight equipment.
- It must not rest on the upper portion of the foot.
- It must be flash- and flame-resistant.
- It must provide complete mobility and flexibility to the aircrew member during operation of the aircraft and related equipment.
- It must be easily donned and removable by the aircrewman without help.
- It must be made of nontoxic and nonirritating materials and must not cause serious complications to wounds.
- It must be nonmagnetic so as not to impair the operation of aircraft instruments.
- It must not cause injuries during a crash or other deceleration.

- It must be compatible with the aircraft seat and restraint systems.

- It must minimize the severity of impact between the lower edge of the armor and the wearer's thigh.

4.4.3.8.2 Ballistic Helmet: In recent years, the Army has supported a program to improve head protection for crew and passengers. This is a problem because of the reduction in mobility that most systems create. When the protection is incorporated into the helmet, the additional problems of discomfort and fatigue are imposed upon the man. Since it is Government-furnished personnel equipment, the design criteria, data, and problems presented are included in this guide to increase understanding and enhance integration with the airframe and equipment design.

An aircrew fragmentation helmet is described in References 44 and 45. It is tentatively designated AFH-1, is made of ballistic nylon fabric with a modified phenolic resin (35 to 40 percent), and weighs about 4 pounds. Its protection (V_{50}) ballistic limit is approximately 1,125 feet per second when measured with a 17-grain fragment simulator. Its impact attenuation characteristics are a big improvement over the typical glass fabric shells. Impact testing of this helmet showed that a 100-foot-pound impact of 7- to 8-millisecond duration generates 90 g, and that a second impact of the same duration in the same site generated only 100 g.

The so-called "ballistic" helmet is not designed to defeat bullets. Its capability of defeating low-velocity fragments and secondary missiles is roughly equivalent to that of the World War II steel helmet. It is more uncomfortable than the standard flight helmet for long-term wear and is more likely to be lost during a crash or similar deceleration. Figure 66 depicts the typical area of the skull that is covered by this helmet.

Experimentation and testing have shown that the maximum acceptable weight for aircrew helmets is 6 pounds. The average time that an 8-pound helmet can be tolerated is 45 minutes; a 9-pound helmet, 30 minutes. The added weight (above 6 pounds) causes shoulder, head, back, and neck fatigue. Difficulty in making rapid head movements, a slight dizziness during low g maneuvers, and a tendency of lightheadedness after removing the helmet have been documented.

The head of an aircrewman in a crash situation is subject to contact with his personnel armor. The addition of a protective helmet tends to increase both the frequency and severity of head/armor contacts. This must be considered in the development of a ballistic helmet.

Ballistic visors are being produced from an improved polycarbonate material that is both flame-resistant and shatter-resistant. The aircrewman's face and eyes can be protected from small-arms fire spall and shattered transparencies by this visor.

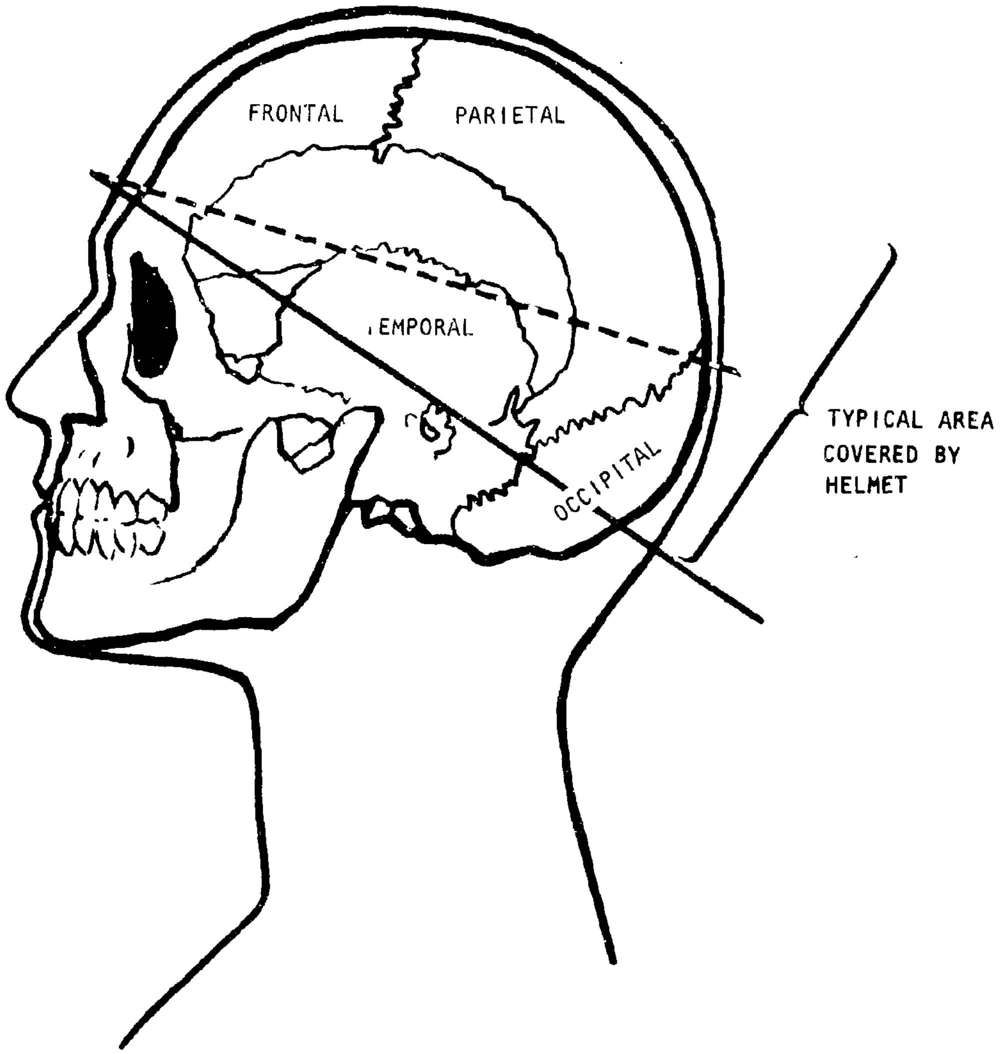


Figure 66. Typical Skull Protection Area.

4.5 FUEL SYSTEMS

4.5.1 INTRODUCTION

Combat experience has consistently shown that fuel system vulnerability to small-arms fire has been a significant cause of aircraft losses. These are due to the large presented area of fuel systems to primary and secondary weapon effects.

Effective protection of the total fuel system is essential in order to minimize aircraft losses. This includes:

- Fuel tanks or cells, cell supporting members, backboard, tank closures, fittings, quantity gages, access doors, and other components
- Tank venting subsystem, lines, valves, and components
- Fuel, refueling, feed and transfer subsystem, pumps, valves, filters, lines, drains, and other components

The protection of fuel systems against ballistic threats has received major design and development attention during every major conflict over the past 30 years. Numerous technical approaches have been devised to prevent loss of fuel supply to engines and to suppress fuel fires and explosions. Both qualified and developmental survivability enhancement techniques are presented in the following paragraphs to provide the designer with the greatest number for consideration.[60-68]

4.5.2 BALLISTIC DAMAGE EFFECTS

Aircraft fuel systems are susceptible to damage and/or malfunction from primary and secondary weapon effects of small-arms fire, including automatic and AA weapons.

Primary ballistic damage effects are those caused by the direct action of the projectile impact. These include:

- Perforation, distortion, tearing, rupture, and shattering of the element struck
- Ignition of fuel vapors and/or liquids by projectile ignition sources (i.e., projectile incendiary material or high-energy impact of aircraft materials)

Secondary ballistic damage effects are those hazardous conditions that may result from projectile impact, that in turn would affect the integrity or operation of the fuel system. These damage effects include such items as:

- Spallation from structures or nearby components
- Liberation of hazardous materials such as oxygen and corrosive battery acid
- Explosive disintegration of hydraulic accumulators, etc.
- High-temperature conditions from damaged hot air lines, or fires from hydraulic or lubrication systems, etc.

Either primary or secondary damage effects can cause failures or malfunctions in elements or components of an aircraft fuel system. The consequence of such failures is related to the failure mode produced by the damage. The basic failure modes associated with most fuel systems are:

- Loss of engine fuel feed (fuel starvation)
- Loss of fuel control management (i.e., loss of throttle control or fuel transfer control, loss of power to or damage of fuel pumps, etc.)

The damage (failure) modes, and the subsequent effects on aircraft survivability, must be evaluated systematically to insure that no major vulnerability of the system is being ignored. An example of a propulsion subsystem flight/mission-essential functional flow diagram is shown in paragraph 4.6. It illustrates the interface with the fuel subsystem required to provide aircraft propulsion.

4.5.3 PRIMARY DESIGN CONSIDERATIONS

Primary protective design techniques are those which have a strong interface with the aircraft functional design and are the basic criteria upon which the detail design techniques depend. They must be applied early in the basic aircraft design and refined as the design progresses. Primary design techniques include the following:

- Tankage location/threat exposure
- Tankage geometry/closures

- Fuel distribution/management
- Fuel characteristics
- Leakage suppression/control
- Fuel line redundancy and separation
- Fire/explosion suppression
- Masking/armor and component concentration
- Component/line placement
- Related design factors (safety, maintenance, repair)

4.5.3.1 Tankage Location/Threat Exposure: Locate fuel tankage to:

- Minimize presented (and vulnerable) areas in primary threat directions.
- Obtain maximum practical tankage and component masking by heavy structure, less critical fuel masses, and less critical components.
- Position less critical fuel above or behind "get home" fuel.
- Minimize fire and explosion hazards from ballistic damage leakage and flow of liquid fuel or vapor to existing or potential ignition sources, and contact with crew or fuel-sensitive components.
- Minimize potential ignition hazards from sources such as engine burner torching, high-temperature bleed air, and electrical or electronic equipment.
- Provide separated redundant fuel tanks.
- Take advantage of external locations to reduce fire and explosion hazards.
- Install self-sealing fuel tanks to permit easy removal and reinstallation for damaged tank repair or tank replacement and structural/airframe repair accessibility.

- Proportion tankage between wing and fuselage to take advantage of more favorable surface-to-volume ratio of fuselage tanks (i.e., lighter weight self-sealing protection and greater resistance to liquid pressure pulse).

- Minimize lengths of critical fuel lines run external to tanks and their exposure to threat effects.

Figure 67 shows the fuel tank installation in the UH-1D/H helicopter. They are located close to the engine, which permits minimal length fuel feedlines. This installation is readily adaptable for use of self-sealing fuel cells and use of internal and external reticulated foam.

Figure 68 is a picture of a self-sealing fuel cell used in the wing of the OV-10 aircraft. Figure 69 is a view of the wing cavity for the fuel cell. Note that foam is installed as void fillers between structure and fuel cell. This serves as a backup to the fuel cell, and prevents the initiation or propagation of a fire in the void area from incendiary projectiles.

Figure 70 shows the self-sealing fuel cell installed and filled with reticulated polyurethane foam.

Combat experience to date has shown this type of installation to be highly effective as a protective feature.

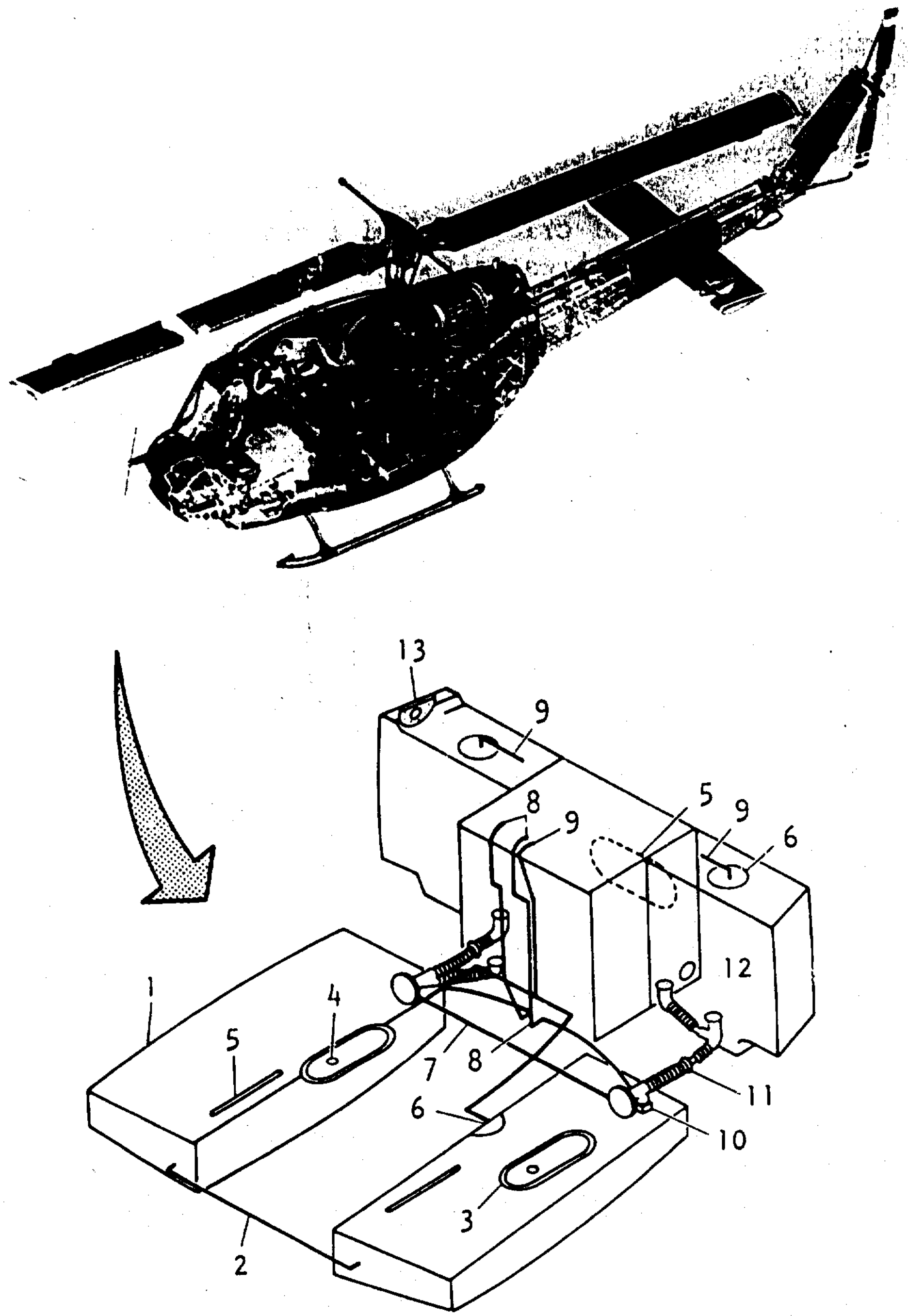
4.5.3.2 Fuel Distribution/Management: The fuel flow configuration and management sequence shall be designed such that the maximum amount of fuel is available to the propulsion system by gravity feed.

Fuel management systems shall be designed to:

- Use fuel from most vulnerable tanks first

- Proportion fuel use so that no tank is completely full or completely empty during the portion of combat missions where small-arms fire can be expected

- Minimize aircraft center-of-gravity displacement problems if fuel capability is lost



1. UNDERFLOOR TANKS
2. FORWARD CROSSFEED
3. SUMP PLATE AREA
4. SUMP DRAINS
5. TANK ACCESS
6. VENT OUTLETS
7. AFT CROSSFEED
8. TANK-TO-ENGINE FUEL LINE
9. VENT LINES
10. DEFUEL VALVE
11. TANK INTERCONNECT LINES
12. AFT VERTICAL TANKS
13. FILLER CAP

Figure 67. Present UH-1D/H Helicopter Fuel System.

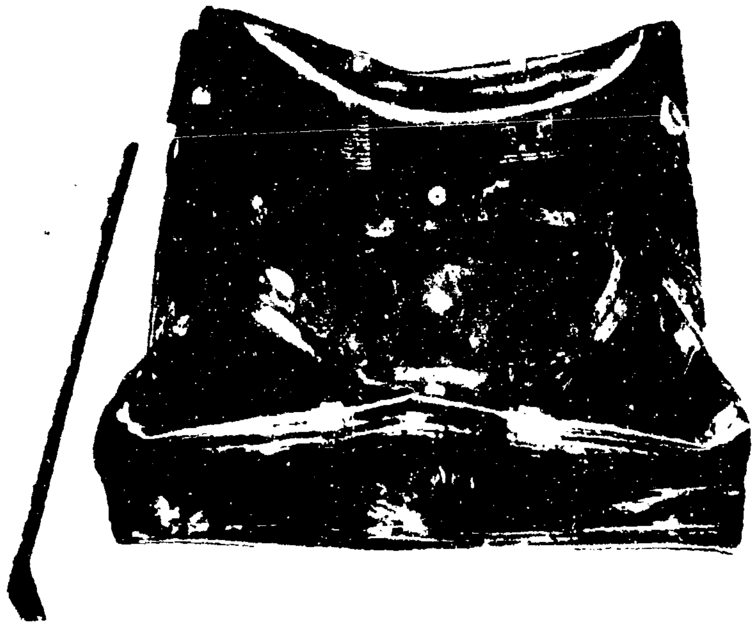


Figure 68. OV-10 Self-Sealing Wing Fuel Cell.

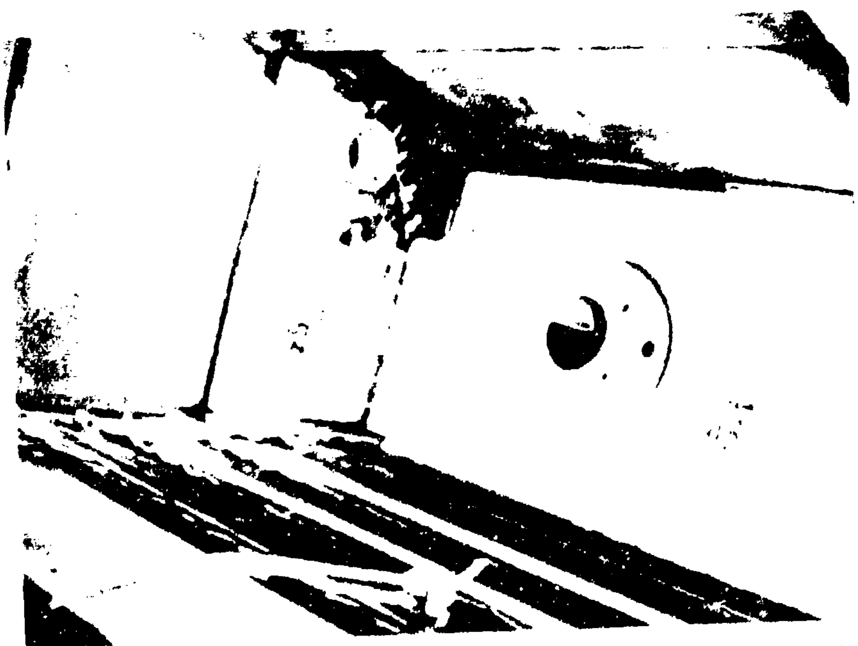


Figure 69. Structure Cavity for Self-Sealing Fuel Cell With Filler Foam.

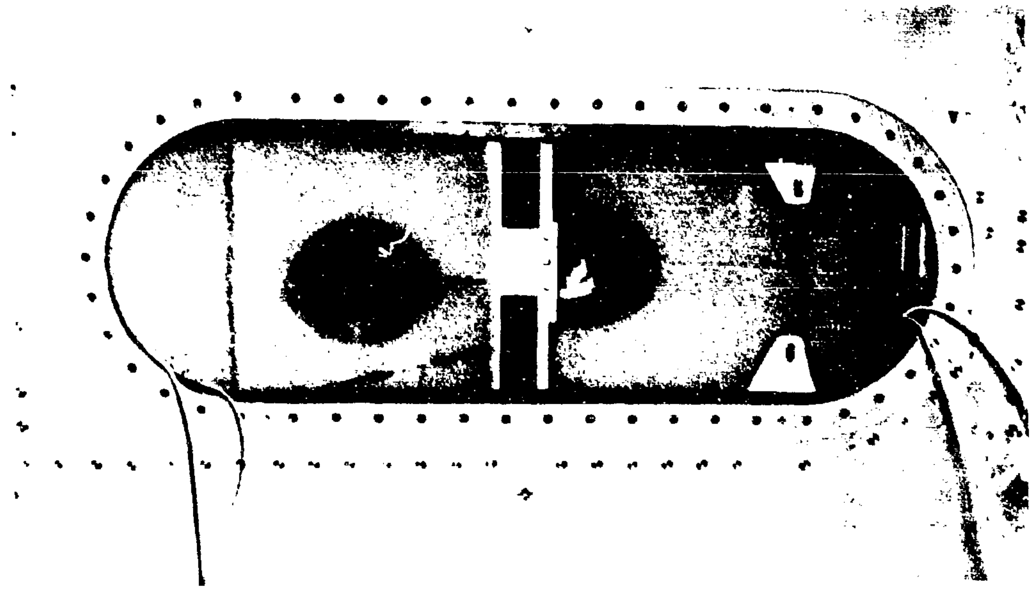


Figure 70. Self-Sealing Fuel Cell Installed and Filled With Reticulated Polyurethane Foam.

Fuel gaging systems shall be designed to:

- Minimize total system failures from single hits

- Provide quantity difference indications sufficiently sensitive to permit detection of fuel loss from specific tanks

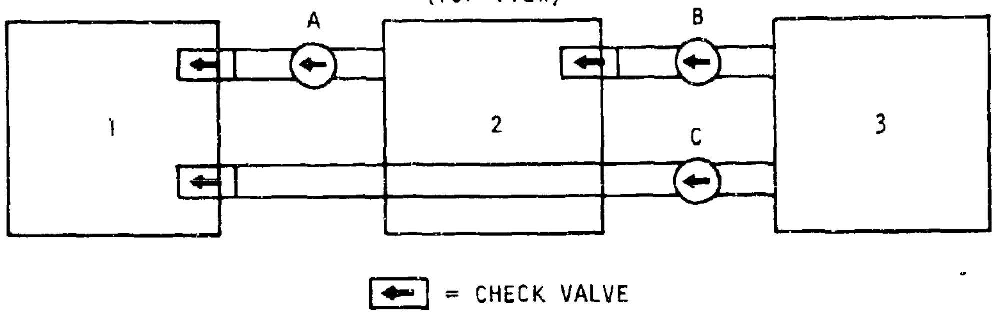
Fuel flow management shall be designed to:

- Provide capability of fuel transfer control that would permit bypassing of damaged fuel tanks to conserve fuel supply. See Figure 71 for a simple schematic of this technique.

- Consider compartmentizing fuel tanks to minimize amount of fuel that can be lost by ballistic damage.

- Detect line leakage with manual or automatic means to isolate damaged line from fuel supply. For example, with two redundant engine fuel feedlines, the damaged line would be isolated by a shutoff valve to prevent loss of vital fuel and minimize fire/explosion hazards.

(TOP VIEW)



(VALVE POSITION)

VALVE	TANK DAMAGE		
	1	2	3
A	CLOSED	OPEN	OPEN
B	OPEN	CLOSED	OPEN
C	CLOSED	OPEN	OPEN

Figure 71. Fuel Sequencing Bypass.

4.5.3.3 Fuel Characteristics

4.5.3.3.1 Conventional Fuels: Conventional fuels include:

- Aviation gasoline - MIL-G-5572
- Jet fuels - JP-4 and JP-5, MIL-T-5624
  - JP-6, MIL-J-25656
  - JP-8, MIL-T-83133, proposed (aviation kerosene)

Each fuel presents fire and explosion hazards having flammability limits, depending upon the fuel vapor/air ratio present. Table XI illustrates jet fuel flammability limits. Note that fuel-air ratios (by weight) are relatively constant, but that volume percentage depends upon fuel volatility.

There are lower and upper flammability limits as follows:

- Lean - fuel vapor/air ratio too low, not enough fuel to burn
- Rich - fuel vapor/air ratio too high, not enough air (oxygen) to burn the fuel present.

Fuel Volatility	Flammability Limits			
	Volume Percent		Fuel-Air Ratio	
	Lean	Rich	Lean	Rich
JP-1				
Minimum	0.62	4.66	0.035	0.28
Maximum	0.71	5.15	0.035	0.27
Average	0.67	4.96	0.035	0.27
JP-3				
Minimum	0.76	5.40	0.035	0.26
Maximum	1.70	7.16	0.035	0.25
Average	0.90	6.15	0.035	0.25
JP-4				
Minimum	0.74	5.34	0.035	0.26
Maximum	0.90	6.15	0.035	0.25
Average	0.80	5.63	0.035	0.26
JP-5				
Minimum	0.57	4.38	0.035	0.28
Maximum	0.62	4.68	0.035	0.28
Average	0.60	4.53	0.035	0.28

TABLE XI. JET FUEL FLAMMABILITY LIMITS (STATIC CONDITION)

Flammable fuel mixtures will burn if brought into intimate contact with an ignition source. Ignition sources include:

- Incendiaries, sparks, arcs, and flames (usually above 1,000° F). These sources usually cause ignition and combustion at the fuel flashpoint, but may also apply enough energy to cause ignition and sustained combustion within a tank well below the fuel flashpoint. Also, combinations may occur with these same sources within a tank beyond the rich flammability limits determined by using low-energy sources.

- High-temperature surfaces above the autogenous ignition temperature (AIT).

Table XII shows flashpoint and autogenous ignition temperature data on military fuels.

TABLE XII. FLASHPOINT AND AUTOGENOUS IGNITION TEMPERATURES		
Fuel	Flashpoint (° F)	Autogenous Ignition Temperature (° F)
Jet Fuel Grade JP-5, MIL-J-5624 (least volatile)	140	477
Aviation Kerosene JP-8, MIL-T-83133	110	473
Jet Fuel Grade JP-6, MIL-J-25656	100	477
Jet Fuel Grade JP-4, MIL-T-5624	-10	484
Aviation Gas MIL-G-5572 (most volatile)	-40	844

Under equilibrium conditions of fuel vapor/air mixing and temperature, there are flammability limits for specification fuels which are temperature and altitude dependent. Figure 72 shows flammability limits for various fuels under equilibrium conditions. Figure 73 shows a comparison of JP-8 fuel and flammable mists with JP-4 fuel. The designer is cautioned that:

- Flammability limits are bands which can vary for individual fuels within their specification limits.
- Flammability limits shift toward higher temperatures for fuel aged or weathered sufficiently to lose volatile constituents by evaporation.
- Under operational conditions, tanks normally do not reach equilibrium vapor distribution states; fuel vapor-air ratios may vary from lean through explosive to rich in different portions of a given tank. The variation can exist as explosive pockets or as stratifications, and will depend upon vent design, tank configuration, vibration, and fuel sloshing. Figure 74 shows a representative distribution variation.

Figure 75 provides an illustration of sloshing effects that can significantly affect flammability limits.

4.5.3.4 Modified Fuels: Extensive research has been conducted to develop modified aircraft fuels with characteristics that minimize fire/explosion ignition and propagation.[67] The feasibility of using such fuels

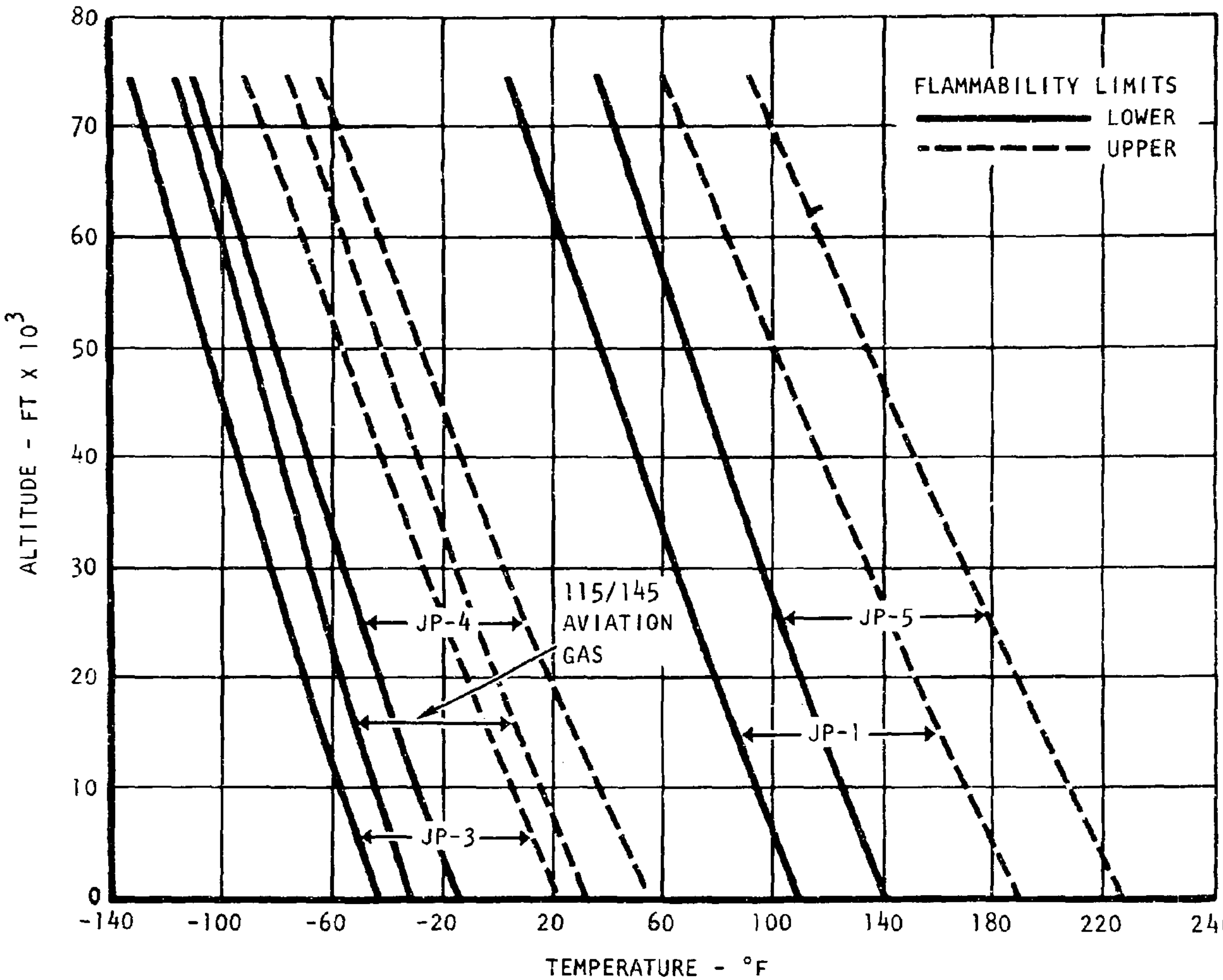


Figure 72. Altitude-Temperature Static Flammability Limits for Various Fuels.

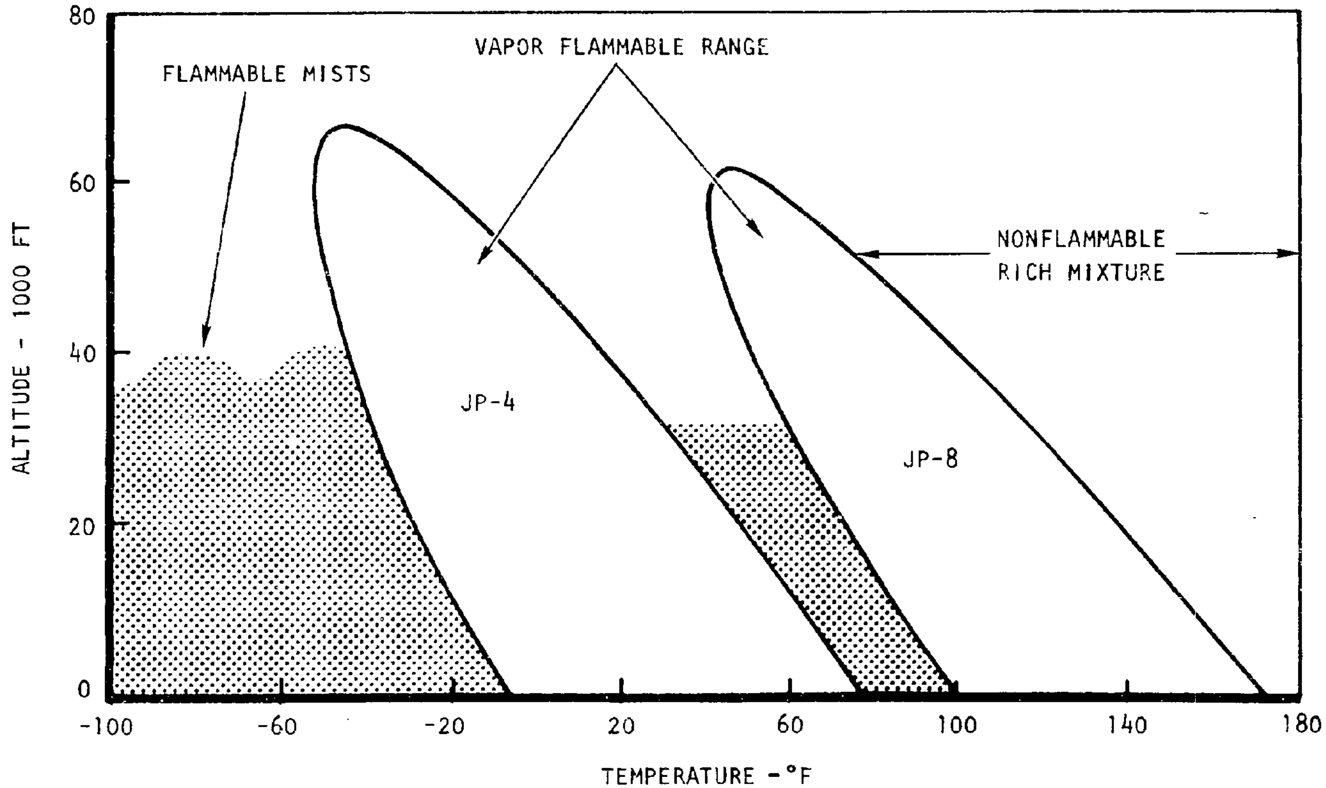


Figure 73. Static Flammability Limits of Fuels of Different Volatility.

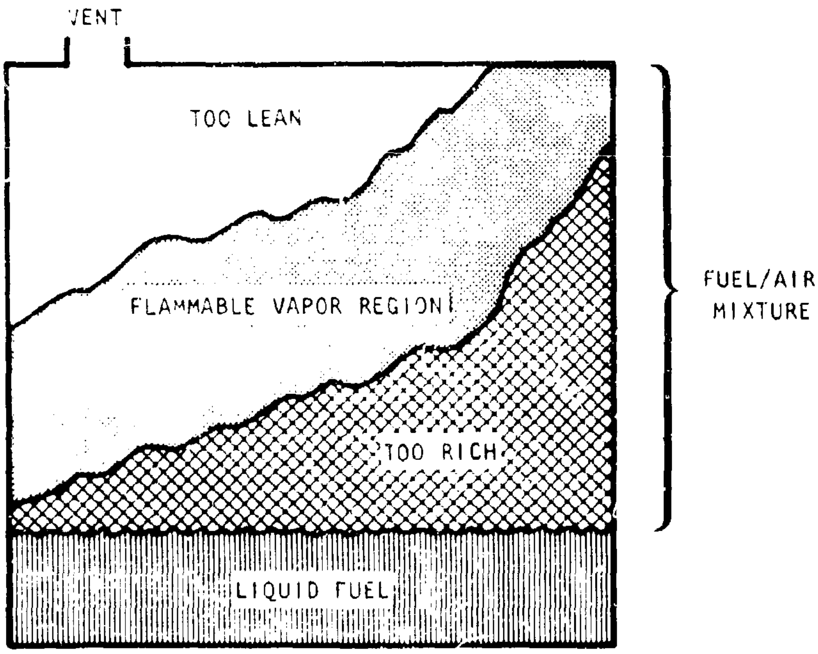


Figure 74. Flammable Vapor Stratification Distribution Layers.

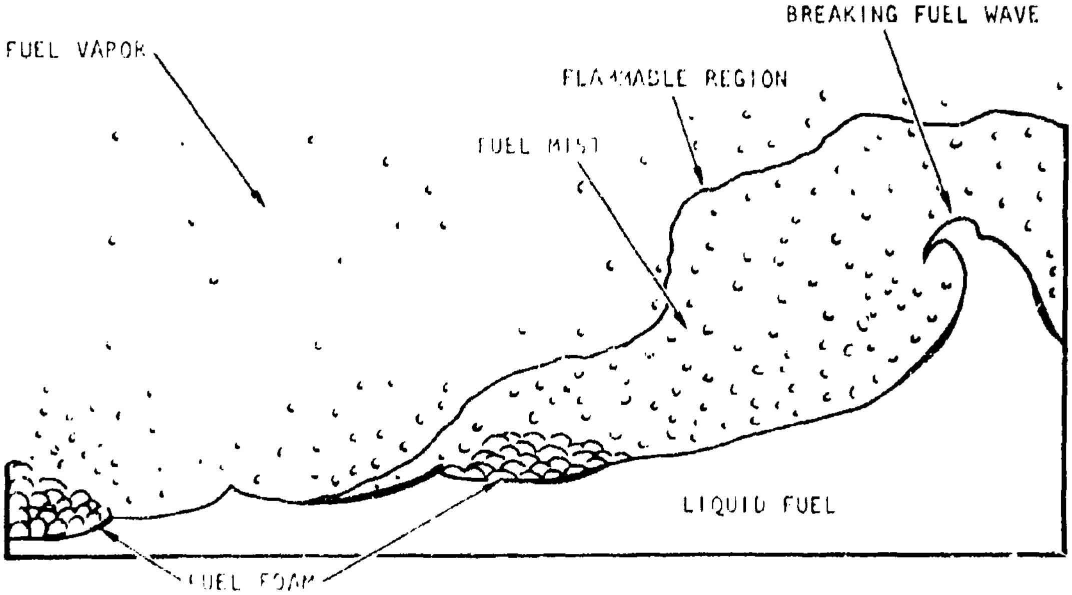


Figure 75. Flammability Limits; Sloshing Effects.

in gas turbine engine operation has been demonstrated. The following three types of modified fuels have been investigated:

a. Gelled fuel - This type is formed by immobilizing fuel particles within a semisolid colloid framework to form a gel. They are designed to inhibit fuel mobility and to depress fuel vapor pressures. Figure 76 compares the vapor pressure of gelled and nongelled gasolines.

b. Emulsified fuel - This type is formed by dispersion of fuel particles within a nonfuel solvent liquid to form a colloid framework of mayonnaise-like consistency. They require longer periods of time for vaporization and formation of an explosive fuel-air mixture. They react well with coagulant-type materials used in self-sealing fuel tanks.

c. Encapsulated fuel - This type fuel is formed by encapsulation of small fuel droplets in microcapsules of polymers, ceramics, or metal. They are highly expensive and have not been fully developed.

The greatest attention has been directed toward emulsified fuels as the most promising candidate to replace existing aircraft fuels for specialized applications. The major benefits that can be realized by use of modified fuels are:

a. Slow rate of explosive vapor formation within a fuel tank. Figure 77 shows a comparison of explosive vapor formation rates between JP-4 jet fuel and the three types of emulsified fuel. As can be seen, two of the modified fuels exhibited nearly a tenfold increase in rate, while the third was over a hundredfold. This reflects a static test condition, however, and is shown for comparison only. Under operating conditions, the equilibrium mixture for Army aircraft fuel systems depends upon the mission profile, altitude changes, fuel consumption rates, slosh conditions, vibration, etc.

b. Reduced leakage from tanks damaged by small-arms fire. The thickened fuel exhibits a significantly lower leakage rate than ordinary fuels through the same size opening.

c. Modified fuel, liberated by battle damage, will burn with less intensity than ordinary aircraft fuels. This results in easier extinguishing of a fire, thereby reducing the requirements for a fire suppression system. By virtue of the slow vaporization

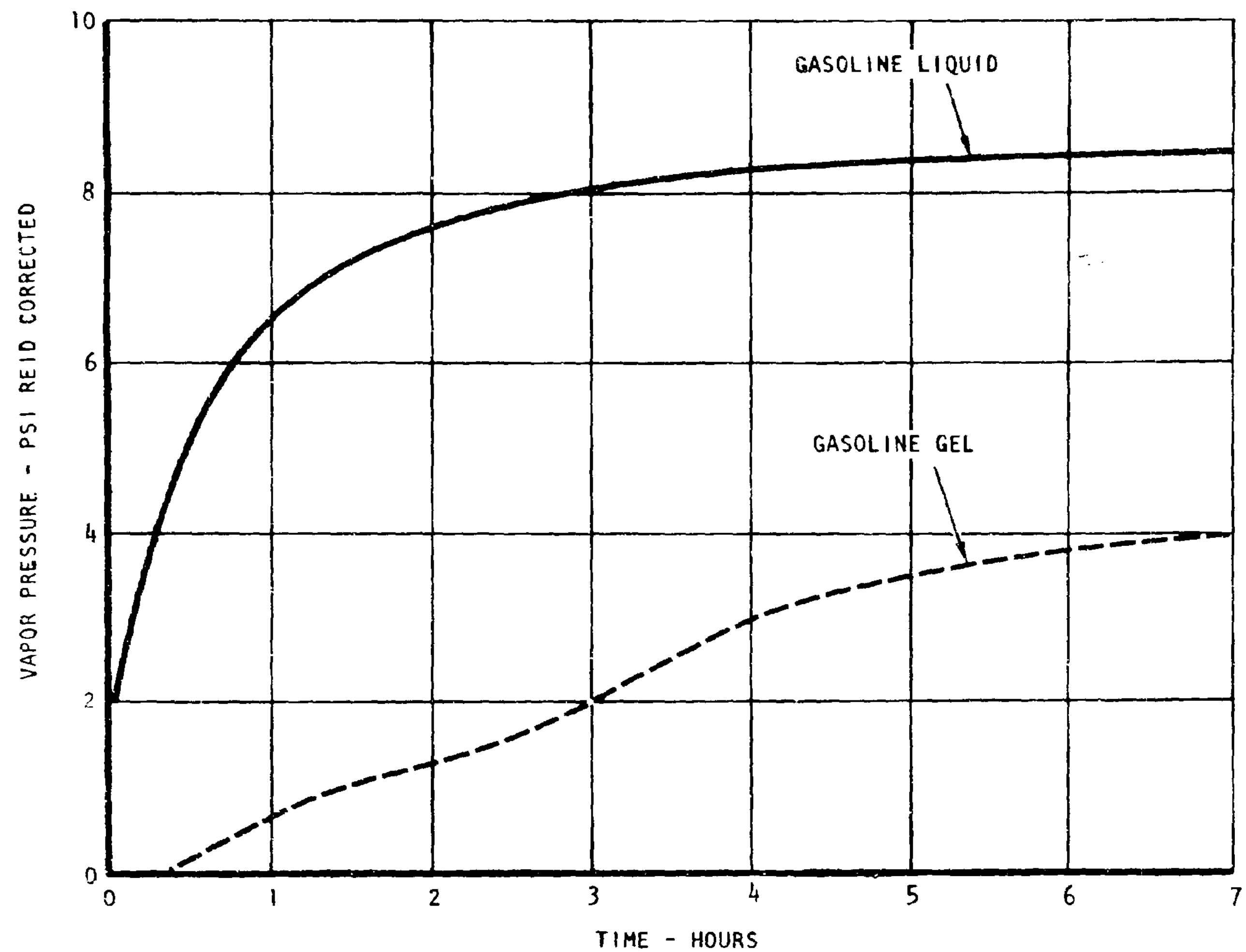


Figure 76. Vapor Pressure of Liquid and Gelled Gasoline.

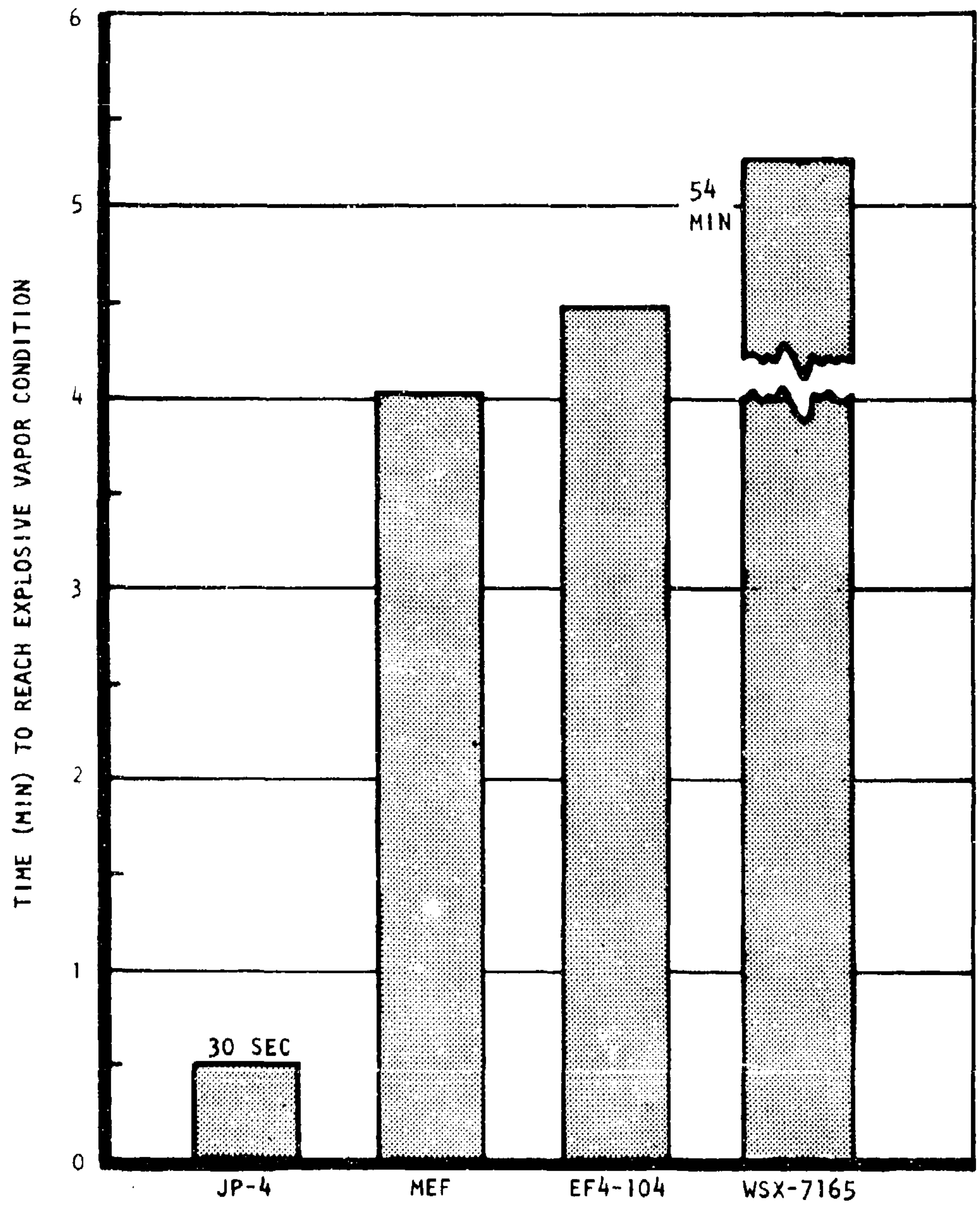


Figure 77. Comparison of Explosive Vapor Formation Rates for JP-3 and JP-4 Emulsified Fuels.

rate of modified fuels, venting of potential leakage areas can be employed to prevent formation of explosive vapors.

d. The probability of postcrash fires is significantly reduced by the use of modified fuels. They do not spray or spread as far from damaged fuel lines or tanks, and burn with less intensity when ignited, thereby enhancing escape of the aircrew following a crash.

There are certain other characteristics of modified fuels that also must be considered in their use in a system. They would, in some instances, be penalties, particularly if the modified fuel is substituted for ordinary types in existing fuel systems. These considerations are:

a. Fuel lines require a minimum of 1-inch inside diameter.

b. High viscous shear-type fuel transfer pumps should be avoided. Emulsified fuel breaks down rapidly from such pumps and defeats the purpose of thickened fuel. Use centrifugal-type pumps with large, unobstructed, smooth contour inlets.

c. Fueling of the tank should be from the bottom to minimize emulsified fuel breakdown.

d. Fuel filter pore size should be limited to no smaller than 115 microns.

e. Teflon (polytetrafluoroethylene) or polycarbonate materials should be used on all system surfaces that the fuel contacts, to minimize fuel flow friction.

f. The walls of the fuel feed tank should incline at a slope not less than 30 degrees, as shown in Figure 78. This provides a "hopper" type container needed to insure proper fuel feed to the pump.

g. Design system to avoid low flow operation conditions that may cause breakdown of the emulsified fuel. Consider bleedoff of engine feed flow back to fuel tank under low flow conditions, as shown in Figure 79.

4.5.3.5 <u>Leakage Suppression/Control</u>: Preventing or minimizing fuel leakage as a result of ballistic damage is essential to insure fuel feed to the aircraft engines and to minimize the probability of fires and/or explosions that could destroy the aircraft. Control of leakage

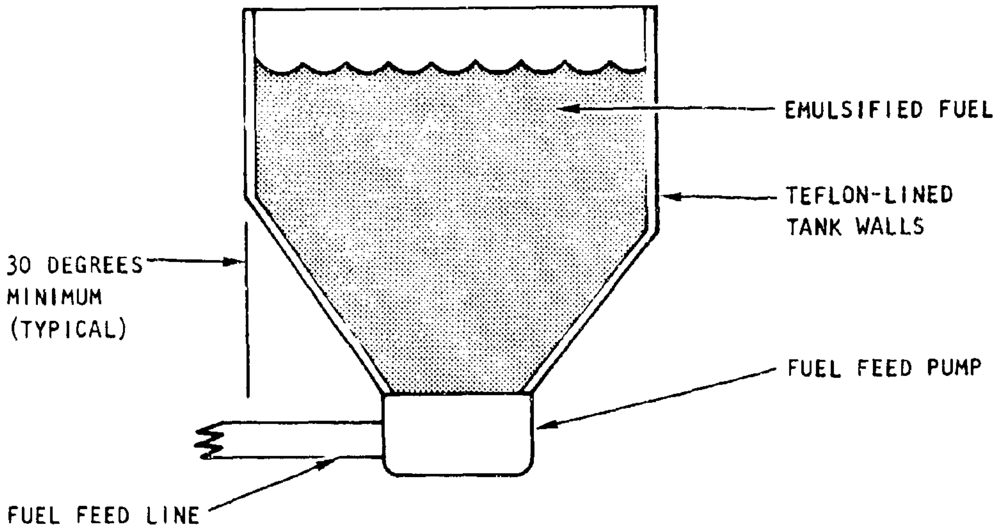


Figure 78. Emulsified Fuel Tank Features.

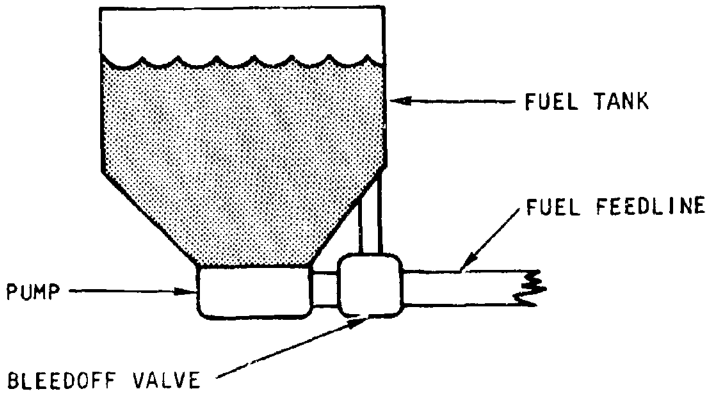


Figure 79. Emulsified Fuel Low-Flow, Bleedoff Design.

that does occur is another important design consideration in minimizing aircraft vulnerability. The following are basic techniques that should be evaluated for use.

4.5.3.5.1 Leakage Suppression: Suppress leakage and enhance self-sealing by considering the following techniques:

- Apply self-sealing concepts to critical fuel tanks, components, and lines.
- Zero tank/vent pressure in combat area with 2 psi as maximum, to promote good sealing and lower weight requirements of self-sealing materials.
- Design for tolerance of liquid pressure pulse (hydraulic ram) effects in tanks, lines, and components containing liquid fuel.
- Consider a suction system with engine-mounted boost pumps for pumping fuel to engine, in lieu of a pressure system with submerged pumps in fuel tanks.
- If a pressure system is used, limit maximum line pressure (boost pump pressure) of 15 psi, to promote good sealing of self-sealing line materials.
- Minimize length of lines outside of tanks.
- Use gravity and suction feed to engine in combat area.
- Provide leak detection and fuel shutoff valve concepts to isolate leakage area.

4.5.3.5.2 Leakage Control: Consider location of all fuel system elements containing fuel, to minimize number and length of potential fuel leakage paths.

Identify, locate, and direct potential leakage paths to avoid:

- Autogenous ignition sources which are normally and potentially present in aircraft.
- Collection of liquid fuel. Locate leakage drain holes, of 3/8-inch minimum diameter, to avoid long leakage paths before exit from aircraft, and reentry of fuel or vapor into hazardous parts of aircraft.

Coordinate leakage paths and venting air to flow in same direction to increase rate of overboard movement of fuel and vapor.

Apply leakage diverter design principles to limit and direct flow of potential leakage. See Figures 80 and 81 for general techniques.[33]

Combine use of leakage diverters and sealants, per MIL-S-8802C, to:

- Confine leakage of liquid fuel and fuel vapor to minimum hazard compartments with safe drainage provisions

- Prevent entry or migration of liquid fuel or vapors to ignition source compartments

4.5.3.6 Fire/Explosion Suppression

4.5.3.6.1 Fire/Explosion Mechanisms: The combustion or explosion of fuel require the intimate association of:

- Fuel and/or fuel vapor in the proper ratio with air/oxygen (combustible material)

- Oxygen (or air)

- Ignition source

Refer to paragraph 4.5.3.3 for information on combustible fuel-air ratios, fuel flashpoints, autogenous ignition temperatures, and altitude-temperature flammability limits for various fuels. Combustible fuel-air mixtures may be ignited by:

- Ignition sources normally in the aircraft having temperatures above the AIT of the fuel are hot engine surfaces, high-temperature bleed air ducts, and high-temperature electronic elements.

- Electrical arcs from shorted electrical or avionic connections and equipment.

Ballistic effects which ignite combustible fuel-air mixtures include:

- Activated incendiary projectiles which accomplish ignition as shown in Figure 82.

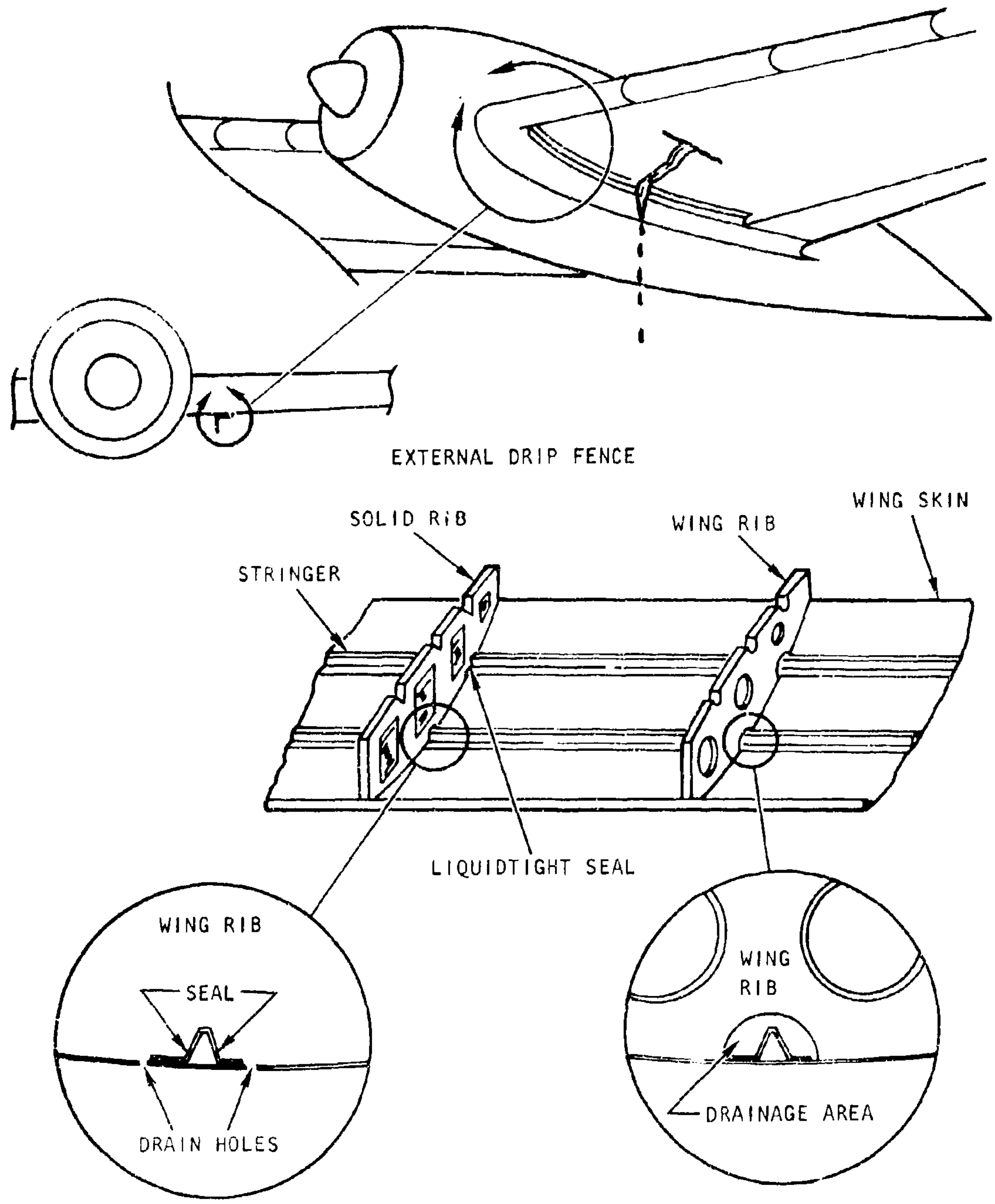


Figure 80. Leakage Diverters.

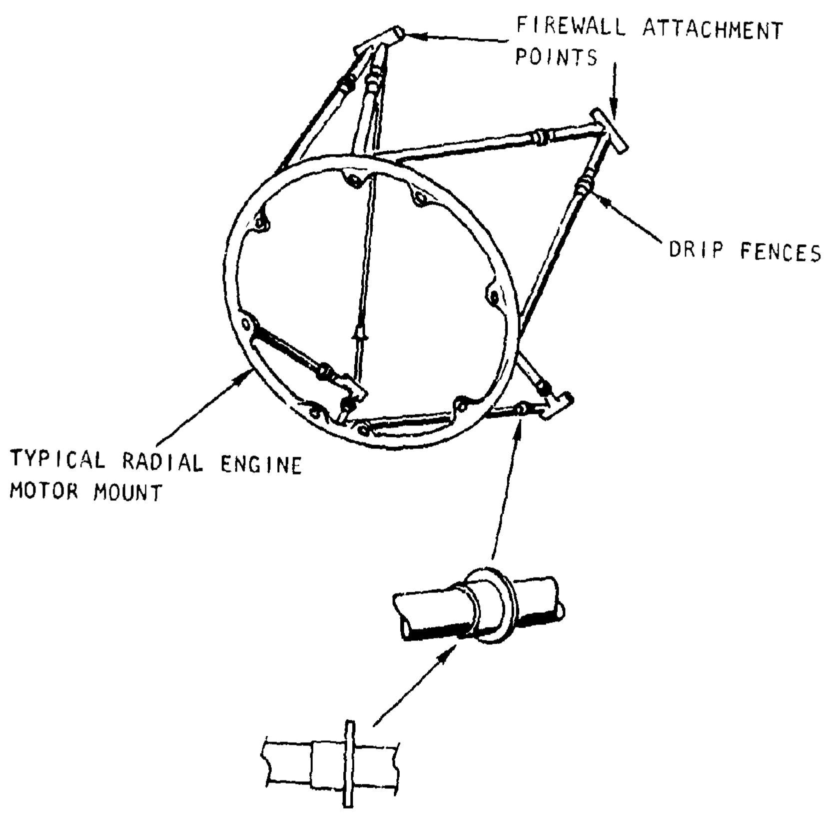


Figure 81. Leakage Diverter Collars.

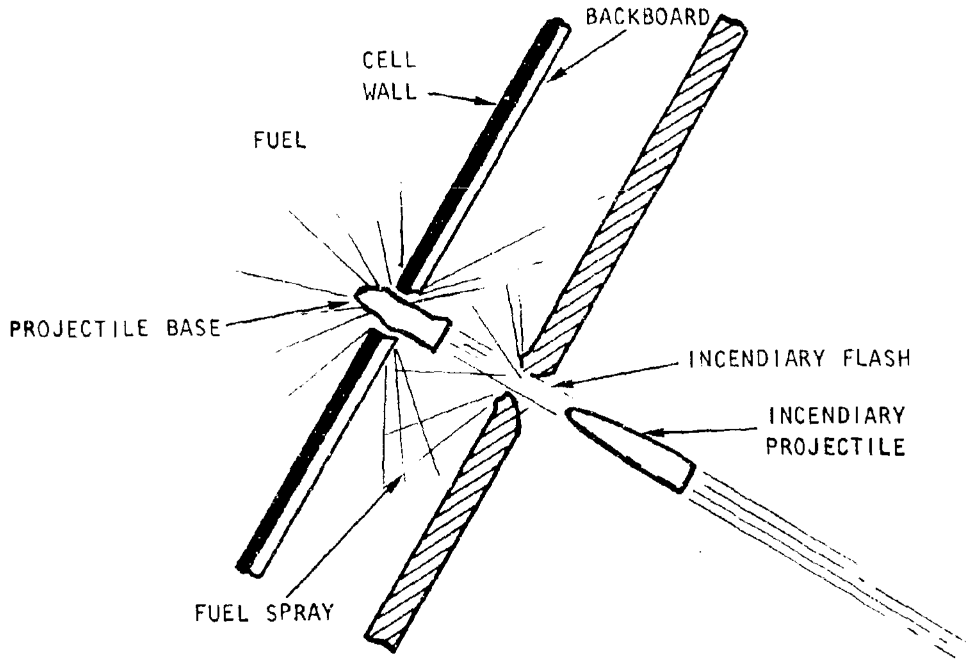


Figure 82. Ignition Mechanism, Activated Incendiary.

- Vaporific flash from high-velocity fragments and spall. The mechanism is given in Figure 83. Figure 84 roughly relates fragment mass and velocity to ignition characteristics.

Combustible fuel vapor-air mixtures may occur in numerous places in the aircraft, including:

- Inside fuel tanks, in the ullage and vent systems
- Adjacent to fuel tanks inside the aircraft mold line (except for mold line walls of integral tanks)
- In compartments adjacent to tanks
- In other compartments where fuel or fuel vapor can collect

Penetrator impact energy is transferred to the fuel during perforation of a tank or other liquid fuel container, and can generate a substantial spurt of fuel. This spurt appears outside the container at both entrance and exit perforations. Each spurt can produce a combustible mixture surrounding the perforation for ready ignition by the penetrator, particularly if it is an activated incendiary or high-velocity secondary fragment.

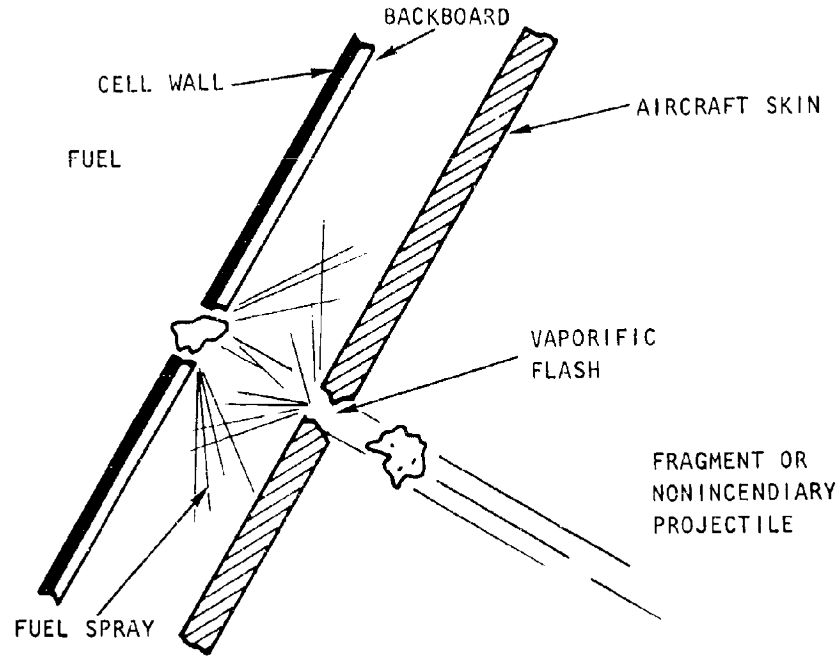


Figure 83. Ignition Mechanism, Vaporific Flash.

4.5.3.6.2 Fire/Explosion Suppression Techniques: Minimize fire and explosion by applying the following techniques:

a. Determine combustion mechanism for each characteristic portion of given fuel system configuration (e.g., tank interiors, tank exteriors, adjacent compartments, other compartments).

b. Apply design techniques to provide for each portion of fuel system an environment which:

1. Is too lean to burn readily (e.g., leakage suppression and high-velocity vent air)

2. Is too rich to burn readily (e.g., inerting, extinguishment)

3. Absorbs ignition or flame propagation energy (e.g., reticulated foam or quench pack)

Care must be exercised in applying the above techniques to also consider the ability of high-energy ignition sources to cause combustion below lean and above rich flammability limits.

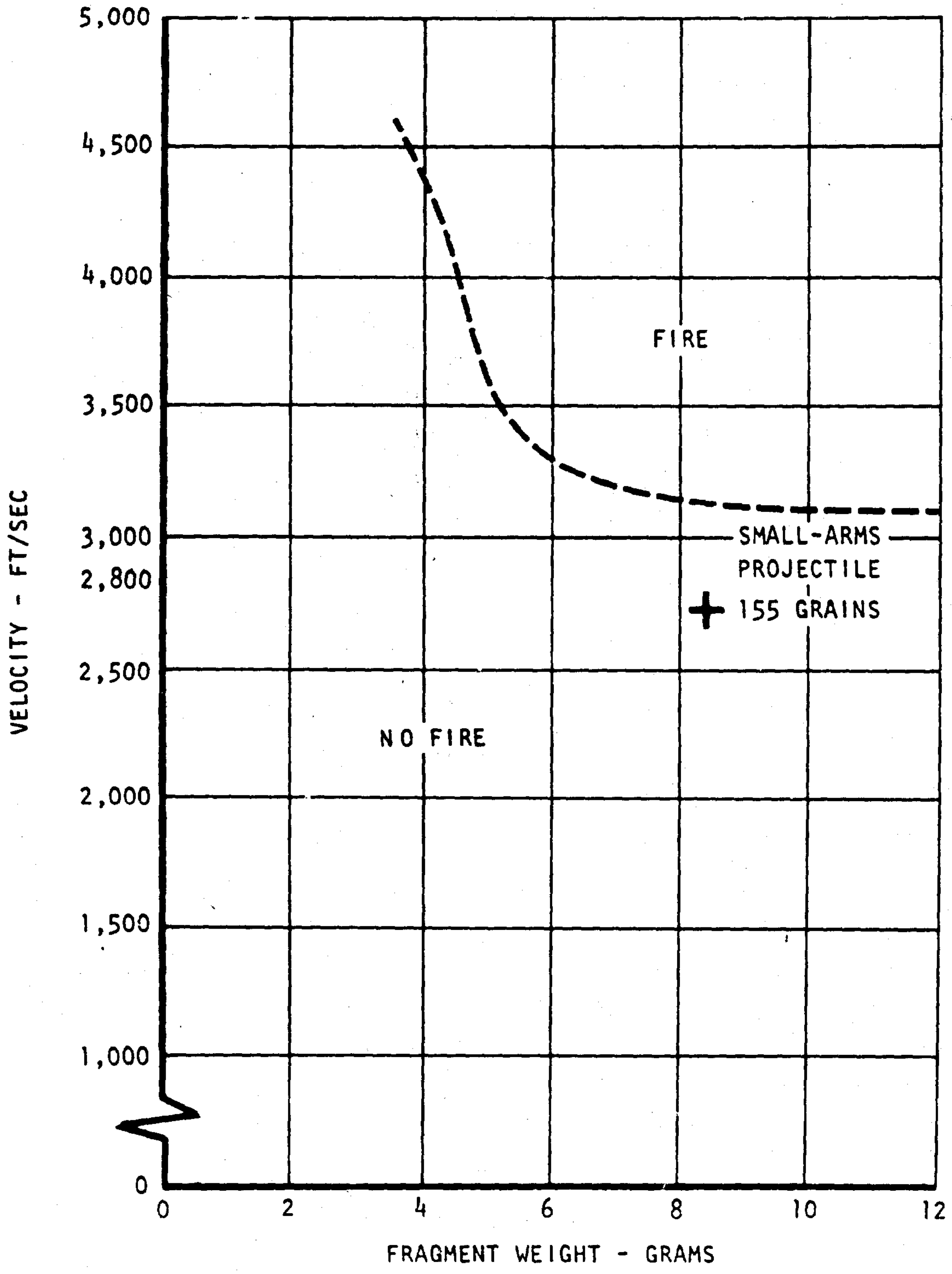


Figure 84. Ability of Fragments to Cause Fire.

Apply fire and explosion suppression techniques to:

- Tank interiors, ullage and vent systems
- Spaces between tanks and mold lines
- Compartments containing tanks and fuel system elements
- Compartments adjacent to tanks and fuel systems
- Other compartments and portions of aircraft where fuel liquid or vapor could appear after ballistic penetration of aircraft sections and fuel system

Specific design guidance is contained in the following detail design section.

4.5.3.7 Masking/Armor and Component Concentration: Consider the following techniques to maximize critical element protection from primary threat directions by:

- Interposing heavy structure
- Interposing less critical components
- Concentration of critical components to minimize armor requirements
- Interposing ballistically significant fuel quantities

Use of heavy structure to mask critical elements must be applied with caution, since light structures can have a low probability of causing the incendiary feature of an impacting projectile to function outside of a fuel tank and, thereby, reduce the probability of igniting the spray of fuel ejected from the tank. The effects of spallation, from projectile impact of thick or heavy section structure, on fuel systems must also be considered. Heavy section structure may also cause projectile deflection into areas where vulnerable fuel system components could be affected.

Fuel may serve as a ballistic mask for fuel system components, other systems, or aircrews. Consider opportunities for masking critical components above, behind, and between redundant or less critical tanks. The value or capability of fuel to slow down a projectile can be approximated by use of a general formula and nomograph contained in TR-71-41B (Volume II).

Apply armor for ballistic protection <u>only</u> after all other protective techniques have been thoroughly exploited, and then only to essential areas such as fuel pumps, etc.

Refer to Paragraph 3.10.3 for armor materials and installation information.

4.5.3.8 Component/Line Placement: Consider the following techniques for fuel system components and lines:

- Minimize components and lines external to tankage
- Separate redundant lines and components so that they are not vulnerable to a single hit
- Concentrate critical lines and components behind adequate masking

4.5.4 DETAIL DESIGN TECHNIQUES

4.5.4.1 Tank Construction: Consider the following techniques for tank construction design:

a. Tank geometry/closures:

1. Minimize vulnerable area of individual tanks in principal threat directions. Avoid complex shapes and attachments which provide stress concentrations and which tend to be ruptured by liquid pressure pulse surges.

2. Design fuel tank system to minimize time that a tank is completely filled with fuel. The fuel level should be lowered as soon as possible, in order to provide a large top surface area of fuel to minimize liquid pressure pulse (hydraulic ram) effects from projectile impacts. This will permit more efficient tank designs to be developed with the same level of protection.

3. Avoid common walls between mission-essential tanks.

4. Avoid spaces over 1 inch between fuel cells and supporting structural walls to minimize fire propagation through intervening space.

5. Locate lines, connecters, and closures to enter and exit in upper, nonfuel wet tank area

6. Design all closures of high-fracture-toughness materials with configurations which provide adequate strength to resist liquid pressure pulse and crash landing forces.[75]

7. Design all tank closure fittings in accordance with MIL-T-27422B, to prevent fuel leakage when separated from fuel system and/or structure by severe threat effects or crash landings.

b. Hydraulic ram protection:

1. Hydraulic ram is produced by a series of pressure waves produced in a relatively noncompressible liquid (fuel) impacted by a projectile or fragment. Hydraulic ram may be more clearly understood as a liquid pressure pulse. The pulse progresses through the liquid radially in all directions from the penetrator. Liquid pressure pulses may include the effects of cavitation, shock waves, and liquid pressure surges. Pulse magnitude is related to the kinetic energy of the penetrator. The pressure can reach several thousand pounds per square inch, close to a .50-caliber AP M2 impact or energy level at muzzle velocity. The pressure decays rapidly with distance from the penetrator.

2. Liquid pressure pulse damage and failure modes can appear as bulging and distortion of tank and structure, both close to the penetrator trajectory and at some distance from it. The high-pressure pulses close to the penetrator tend to cause severe bulging, cracking, and tearing of tank wall and structure around entrance and exit perforations.

3. Figure 85 shows an OV-10A self-sealing wing tank hit by a .50-caliber AP M2 during testing. Note bulging of lower skin and failure of rivets.

Minimize damage from liquid pressure, using appropriate combinations of protective design techniques, including:

- Maximize volume of fuel in each tank to avoid small tanks. Liquid pressure pulse attenuation is dependent upon the fuel mass available to absorb it. Small (low volume) tanks, if unavoidable, can be made survivable, provided they are shallow and are not totally filled during exposure to small-arms fire.

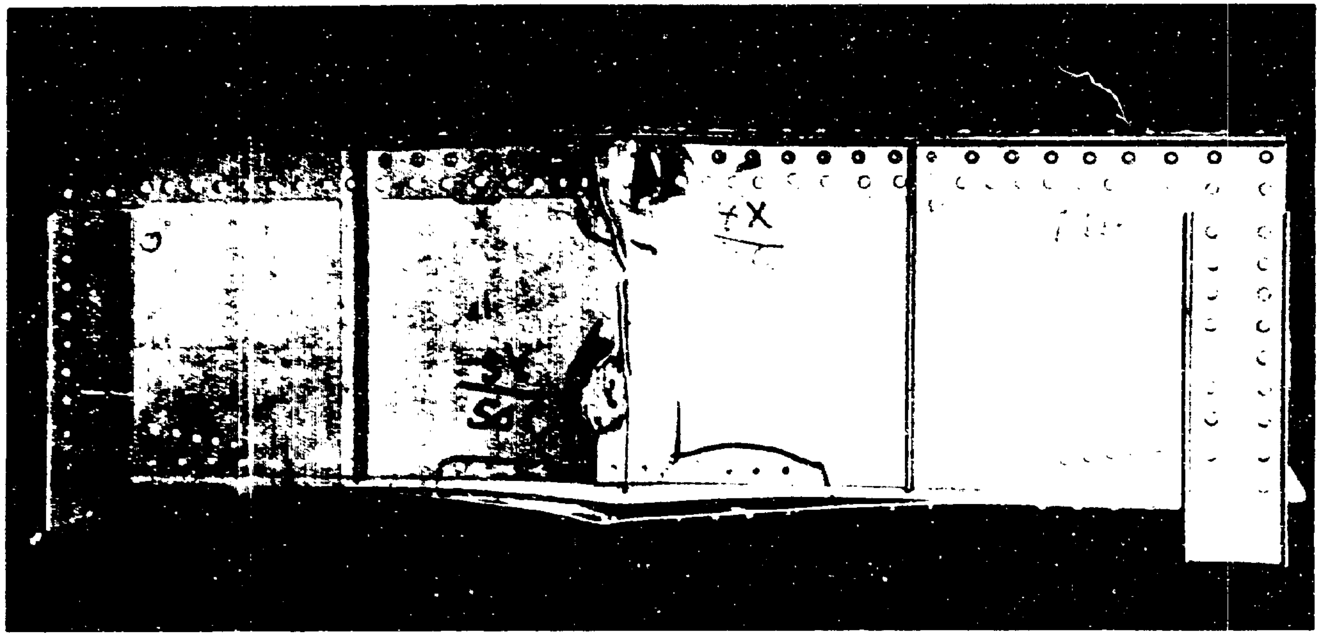


Figure 85. A-7A Wing Tank Liquid Pressure Pulse Damage.

- Use smooth, simple tank contours with shapes and structures designed to resist internal pressure.

- Avoid narrow, complex tank shapes and abrupt section cutouts.

- Maximize flexibility of tank structure and fuel cell. Liquid pressure drops rapidly with relatively small displacement of fuel.

- Integrate self-sealing cells and backboard concepts to enhance flexibility.

- Apply crash-resistant tank (MIL-T-27422B) and structural concepts.

- Consider use of reticulated foam (MIL-B-83054) to attenuate liquid pressure pulse.

- Use self-sealing tank materials.

Consider self-sealing for all tanks, except externally carried tanks and integral tanks having a majority of tank surface common to aerodynamic mode line surfaces. Design in accordance with MIL-T-5578C, MIL-T-6396B, MIL-T-27422B, and MIL-V-27393A.

Use nonstructural, compartment self-sealing tanks supported by backboard.

Design so that fuel container rests within and is supported by structure, but does not carry airframe loads. The fuel container may be a metal or plastic tank, but it usually is an elastomer bladder cell or an elastomer self-sealing cell. The tanks and cells carry only local loads imposed during installation, and such loads as vent pressure, fuel head pressure, liquid pressure pulse surges, and fuel slosh and acceleration loads. These loads are transferred through the self-sealing and backboard into the aircraft structure surrounding the tanks.

Consider use of MIL-T-27422B crash-resistant self-sealing tanks where installation and related factors permit. Effective self-sealing is accomplished by conventional self-sealing cells installed inside the airframe. These cells are of multilayer elastomeric construction made, from the inside out, of a fuel-resistant inner ply, a fuel vapor barrier layer, alternate layers of fuel-sensitive elastomer sealant, and plies of elastomer-coated fabric plus a fuel-resistant outer coating. Fabric plies are usually concentrated on the exterior of the sealing material

construction to support the sealing layers against fuel head pressure during the sealing action and to transmit fuel loads to backing material and supporting structure. These outer plies resist bursting and tearing from the liquid pressure surges, and also serve as bonding areas for installation straps, if required, to support the weight of upper portions of an empty fuel cell. The other ends of the installation straps are drawn up and attached to the airframe.

Minimize fuel tank internal pressure to 2 psig or less (zero gage pressure preferred), when in combat area, to enhance sealing and to reduce weight of self-sealing material.

Minimize self-sealing weight by minimizing thickness of or eliminating self-sealing material in upper portions of fuel cells. If fuel is not in contact with the upper portions of the cell during combat, weight may be saved in this area by using the tear-resistant bladder cell construction without sealant. Reduced sealant thickness may be used where fuel pressure and fuel head are low. The cost of fuel cell fabrication may be only slightly increased by modular variations in sealant thickness. The lighter weight cells can be used in "good" installation, with adequate thickness of backboard.

Design cell installation openings in airframe to be of adequate size to avoid installation damage to fuel cells and backboard. Conventional flexible self-sealing cells can be folded, and even rolled, into relatively small bundles for placement in the fuel cell compartment.

However, if the installation opening is too small, the flexible cell must be folded so tightly that damage is likely. This cell damage may not be detectable for some time until fuel swells the sealant and progressive disintegration of the cell has started.

Select minimum self-sealing cell thickness providing acceptable sealing probabilities. Table XIII gives sealing material construction parameters for various threats at near-muzzle velocity. This information was compiled from supplier's data. Consider light constructions for installations substantially in accordance with protective criteria of this design guide. Apply construction where protective criteria must be compromised by other design considerations.

Typical cell constructions from various suppliers are shown in Table XIV.[32] Consult with suppliers for latest improved designs.

Refer to Table XV for general criteria for satisfactory sealing.[61] Selection of the self-sealing cell depends primarily upon definition

TABLE XIII. SELF-SEALING CELL CONSTRUCTIONS VERSUS THREAT

Threat Level	Cell Type	Areal Weight (lb/sq ft)	Thickness (in.)
0.30 cal	Light	0.43 to 0.49	0.076 to 0.102
	Medium	0.54 to 0.64	0.10 to 0.122
	Heavy	0.77	0.147
0.50 cal	Light	0.824 to 0.86	0.158 to 0.173
	Medium	1.06 to 1.15	0.214 to 0.217
	Heavy	1.2	0.247
14.5 mm	-	1.7	0.346

of the threat effects. Both the kinetic energy and the characteristics of the projectile or fragment must be considered. Large tanks may seal better than smaller tanks. Tanks with more pressure-resistant shapes tend to seal better.

Select fuel cell backboard for compatibility with tank configuration and design. Use low-modulus backboard if tank support spacing does not permit excessive cell sagging under fuel loads.

Backboard used effectively with self-sealing fuel cells provides satisfactory sealing with a minimum combined weight of cell and backing board. The backboard is distorted and torn less than the airframe structure and skin in the vicinity of the perforation. Thus, it can provide support for the self-sealing material and align the perforation edges to allow effective sealing, even if external structure is locally torn away. Sealing capabilities are enhanced if self-sealing materials do not sag under fuel head loads. Also, penetrator impact may cause flowering and petalling of skin and structure. The backboard prevents these metal projections from entering the perforation and holding it open, preventing sealing. The types of backboard presently being used include high modulus (MIL-P-8045), low modulus (ARM-18 and ARM-21), honeycomb panels, and semirigid plastic foam.

TABLE XIV. SELF-SEALING TANK MATERIALS

Manufacturer and Designation	Protection Level Caliber	Gage (in.)	Weight (lb/sq ft)	Qualified MIL-T-5578 Level	Installed in
Firestone					
1316.3	.30	0.210	1.01	B	Army Air
1451	.30	0.118	0.57		Boats
Goodyear					
FTL-13	.30	0.100	0.543	B	S-64, S-61, HH-3C
Uniroyal					
US 179	.30	0.122	0.64	B	
US 180	.30	0.102	0.49	B	AH-1G, OV-10, FH-1100, LOH
Firestone					
1146	.50	0.240	1.310	A	A-4E, TA-4E
1550-1	.50	0.184	0.938	A*	
Goodyear					
FTL-11-13	.50	0.247	1.200	A	B-47, F-84F,
FTL-17	.50	0.170	0.855	A	F3H, F-101,
ARM-061A	.50	0.178	0.909	A*	UH-1
Uniroyal					
US 173	.50	0.217	1.15	A	A-7A
US 182	.50	0.173	0.86	A**	
US 750	.50	0.216	1.07	A*	

*Also meets MIL-T-27422B

**With Conolite B33FG1W backing board

High-modulus backboards are constructed of fiber glass epoxy laminations with different fiber directions in adjacent plies. Facing materials include DuPont Nomex, polyurethane, or the matrix material itself. Backboard thickness usually ranges from 0.023 to 0.070 inch,

TABLE XV. GENERAL CRITERIA FOR SATISFACTORY SEALING

Given Threat: .50-Caliber AP M2, at 2,900 fps (13,000 ft-lb)

Sealing Effectiveness Parameters	Satisfactory Criteria
Fuel Volume (gal)	≥80 (10.7 cu ft)
Surface-to-Volume Ratio (sq ft/cu ft)	≤3.3
Pressure Surge Attenuation, Reticulated Foam, MIL-B-83054	Filled with foam*
Fuel Level in Tank	≤Full**
Tank Pressure (psi)	≤2***
Structural Rigidity	≤Conventional center fuselage
Self-Sealing Cells (lb/sq ft)	≥0.86
Fuel Cell Backboard	
Goodyear ARM-18 (lb/sq ft)	≥0.038
Air Logistics 700 SIEBNN (lb/sq ft)	≥0.040

*Installation did not meet MIL-T-5578C self-sealing requirements without foam.

**Full fuel tanks are not recommended for survivability enhancement. This table entry illustrates that tanks full of fuel can be self-sealing against .50-caliber AP M2 at 13,000 ft-lb if other listed requirements are met. The total installation would undoubtedly be lighter for the same sealing performance if the tank were not full of fuel.

***Sealing was about 80 percent effective at 6 psi.

depending on installation, load, and threat requirements. Table XVI summarizes the backboard data. Backboards may be obtained as flat sheets which may be bent to simple contours. If compound contours or sharp bends are required, the backboard may be premolded to fit the particular application. Backboards may be attached to aircraft structure with flattop fasteners such as blind and cherry rivets, or with fuel-resistant adhesives. Installations should be designed with a minimum number of attachments, to allow the backboard to deform with impact in

TABLE XVI. BACKING-BOARD MATERIALS

Manufacturer and Designation	Protection Level Caliber	Gage (in.)	Weight (lb/sq ft)	Spec
Air Logistics				
700S1-ESNN-23	.30	0.023	0.22	MIL-P-8045
700S1-EBOO-37	.50	0.037	0.37	MIL-P-8045
700S1-EBNO-39	.50	0.039	0.39	MIL-P-8045
700S1-EBNN-41	.50	0.041	0.41	MIL-P-8045
Conolite				
	.30	0.026		MIL-P-8045
	.30	0.033		MIL-P-8045
	.50	0.060		MIL-P-8045
Firestone				
F1-41	.50	0.800	0.41	MIL-P-8045
B-2	.50	0.080	0.41	MIL-P-8045
Goodyear, Arizona				
ARM-18		0.070	0.35	MIL-P-8045
ARM-021		0.070	0.28	MIL-P-8045

order to absorb ballistic energy. Low-modulus, energy-absorption materials have been developed which perform well as backboards. They have performed well in gunfire tests, and their higher impact strength (135 ft/lb compared to 41 ft/lb for typical MIL-P-8045 fiber glass epoxy material of about equal weight) may offer advantages for high-level threat applications. The lower modulus, higher elongation characteristics of the ARM-18 may afford opportunities for dissipation of liquid pressure pulse forces. ARM-18 is not as stiff as fiber glass and presents some cell support problems.

Two additional backboard concepts have been successful in specific applications. Honeycomb panels with aluminum core and glass reinforced plastic face next to the fuel cell have been successful in installations where liquid pressure pulse from projectile impacts has not been severe. Liquid pressure pulse tends to delaminate honeycomb panels. Semirigid plastic foam has functioned well as a combined backboard and void filler. However, this foam tends to transmit fuel loads to the skins, and is likely to damage skins and skin attachments.

4.5.4.2 Ullage Environments and Explosion Suppression: If an ignition source is present, the occurence of fire or explosion inside fuel tanks depends upon fuel characteristics, as influenced by aircraft operating conditions and tankage configuration in developing flammable ullage conditions. Ascent (increase in altitude) can result in lower fuel vapor pressure and increased evaporation rate from the fuel surface. This, in turn, can create a richer fuel/vapor ratio in the tank ullage space. This condition is a function of:

- Air inlet/outflow at the tank vent
- Fuel usage rates
- Changes in altitude
- Effect of vibration and vapor pressure (i.e., altitude and temperature) on fuel surface evaporation rate

Penetrator impact, fuel sloshing, and fuel tank vibration can produce flammable fuel mists and foams (too lean or too rich to burn) for some portions of fuel tank ullage for almost all flight profiles of Army aircraft. Figure 86 shows the relationship of maximum fuel explosion pressures to the fuel-air ratios (by volume) for sea level and 30,000-foot altitudes.

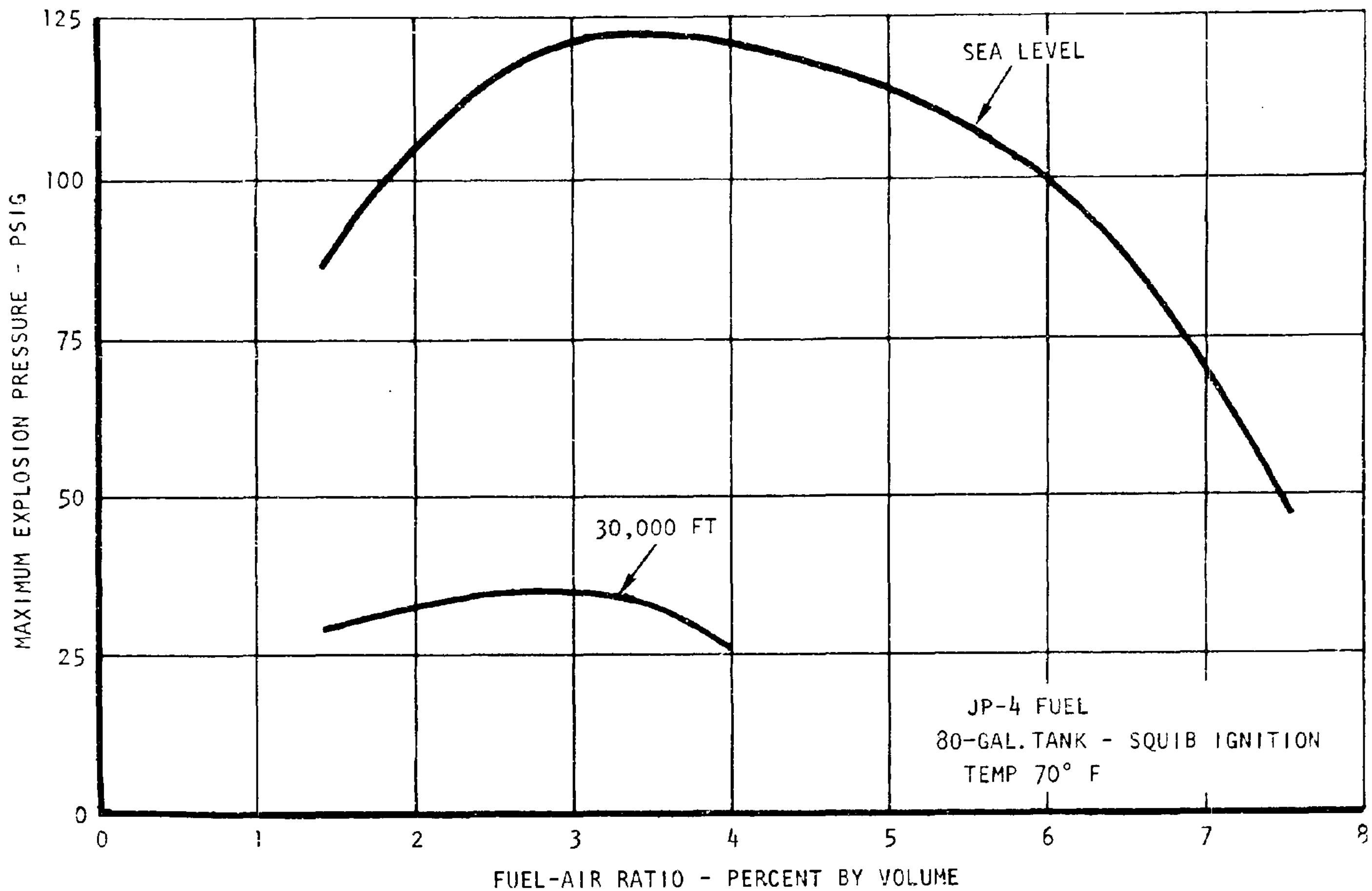


Figure 86. Tank Explosive Pressures.

Consider alternative basic suppression systems for fire and explosion, including:

- Reticulated polyurethane foam
- Inerting systems
- Detection and suppression systems (still in evaluation for fuel tank explosion suppression)

4.5.4.2.1 Reticulated Polyurethane Foam Baffling Material: Polyurethane foam material, per MIL-B-83054, is effective for fire and explosion prevention inside fuel tanks. It prevents propagation of a flame front in a closed space. However, a block of the foam will melt and burn if its free surface is exposed to a continuous supply of oxygen and a sustained ignition source. Reticulated polyurethane foam has significantly reduced liquid pressure surges and hydraulic ram effects from projectile impact. It also has multihit protection capability. Consider the following alternative designs for installation of reticulated foam:

a. Full Pack - install foam to completely fill tank except for cutouts for fuel outlet and vent inlet.

b. Void Pack - in some installations, spaces between firmly mounted foam blocks resulting in 40-percent void volume have provided adequate attenuation of flame fronts (pressure rises less than 5 psi) through explosive fuel vapor-air mixtures. Voided installations are configuration sensitive; the effectiveness of flame-front suppression of the given design must be verified by ballistic incendiary test.

Table XVII contains basic design information on reticulated foam.[32]

4.5.4.2.2 Inerting Systems: These systems can prevent the initiation of a combustion reaction by reducing the oxygen concentration to below the combustible limit within the fuel tanks and vent system. See Figure 87, which indicates the oxygen limit required to prevent combustion. As can be seen, below a 10,000-foot altitude, there is only a slight change in the maximum oxygen limits.

TABLE XVII. DESCRIPTION OF RETICULATED POLYURETHANE FOAM BAFFLING MATERIAL, FUEL TANK, MIL-B-83054

Function	Passive: explosion proofing, fire suppression, shock attenuation inside fuel tanks.
Configuration	Reticulated polyurethane foam: open pores, 10 pores per inch, three-dimensional net-like polyurethane elastomer material.
Principle of Operation	Suppresses explosions and flame fronts by absorbing radiant and sensible heat on its large, complex surface area, dissipating combustion energy and literally cooling the flame. Attenuates shock by shock wave diffraction from large complex surfaces; absorbs and dissipates energy by tearing and elastic and plastic deformation.
Application Constraints	Install under 3 to 6 percent compression. Design foam blocks to fill complex tank, plumbing, and component configurations. Allow cutout areas for vent gas flow and high rate fuel flow.
Performance	Excellent fire suppression with conventional fuels through full range of fuel-air ratios and operational altitudes. Shock wave attenuation is effective.
Penalties	Weight added and fuel volume lost.
Weight	2 pounds per cubic foot, dry
Temperature Limit	285° F
Volume	3 percent

TABLE XVII - Continued

Fuel Retention	1.5 to 2 percent (fuel which does not readily drain)
Fuel Contamination	When new, does not exceed contamination limits for fuel.
Availability	Good. Supplied as "buns" (40 x 80 x 8 inches) or "blocks" cut to size with band saw or hot wire.
Maintainability	Little maintenance required. Periodic inspection for debris and contamination pickup from fuel. Blocks of foam torn by battle damage should be replaced to minimize debris.

Inerting with nitrogen can be accomplished by three different types of systems which:

a. Reduce oxygen concentration by dilution, feeding nitrogen into tanks as fuel is consumed or as decreases in altitude require flow of gas into the tanks to balance external ambient pressure.

b. Reduce oxygen concentration by purging; that is, sweeping out the air/fuel vapor mixture in the tank and vent system with nitrogen.

c. Disperse fine bubbles of nitrogen into the fuel near the tank bottom, scrubbing the fuel of dissolved oxygen, and purging the tank ullage and vents. This system prevents release of dissolved oxygen from the fuel, tending to produce explosive ullage vapor mixture after exposure to high altitude.

Consider:

a. Liquid versus gaseous nitrogen storage. Design high-pressure gaseous storage bottles to resist shattering by penetrator impact.

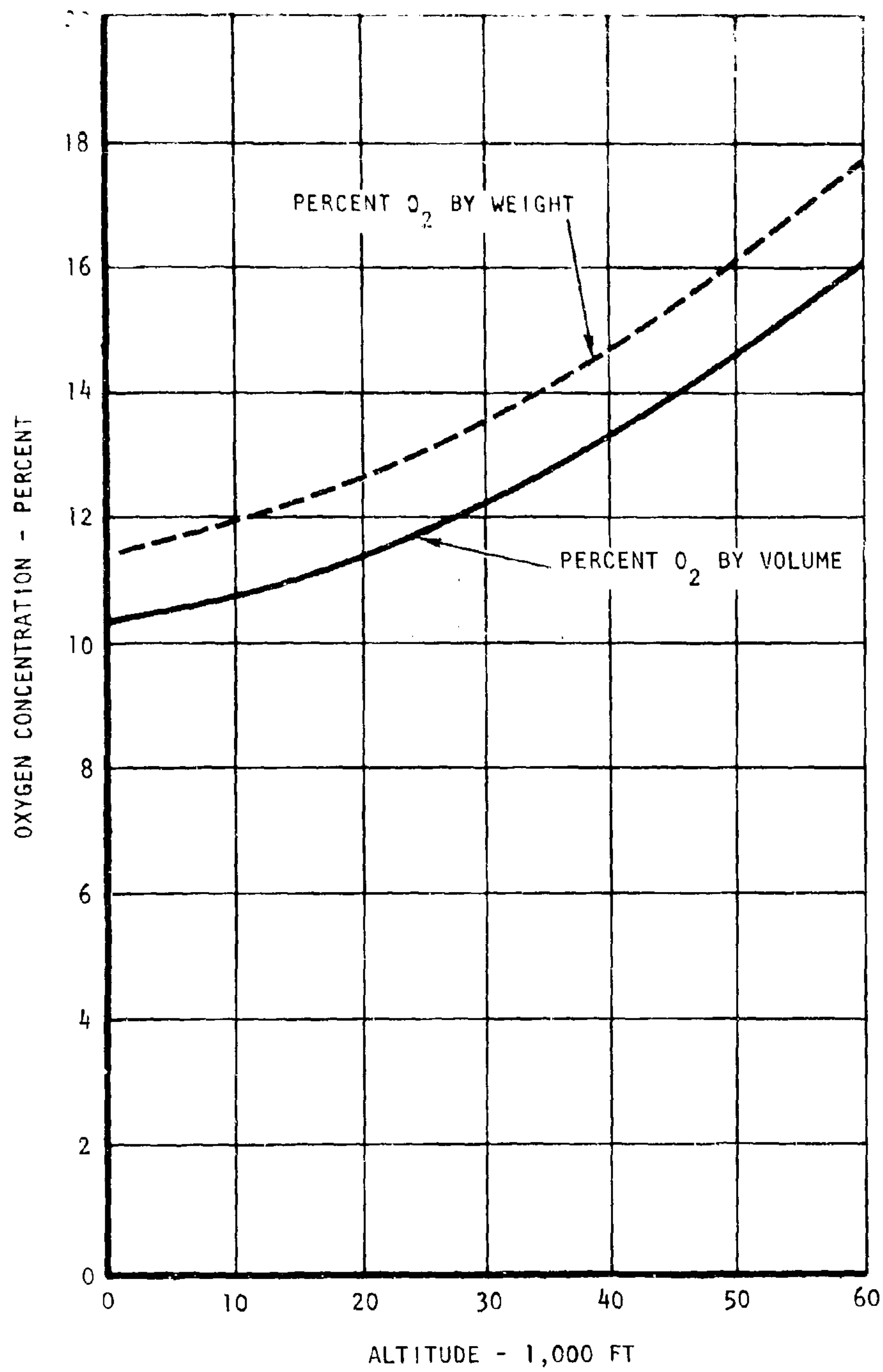


Figure 87. Maximum Oxygen Limit in Inerted Fuel Tanks.

b. Nitrogen rather than other inerting gases, because of its availability and low absorption by fuel

Minimize nitrogen storage bulk and weight by designing to:

- Specific design missions with minimum excess nitrogen capability
- Minimum ullage gage pressure in combat zone to reduce nitrogen losses from ullage perforation

Table XVIII describes gaseous and liquid nitrogen inerting systems .32 Figures 88 and 89 show schematic diagrams of typical gaseous nitrogen inerting systems, and Figure 90 shows a schematic diagram of a typical liquid system.

TABLE XVIII. DESCRIPTION OF NITROGEN INERTING SYSTEMS

Function	Active: explosion proofing and fire prevention inside fuel tanks.
Configuration	Liquid or gaseous nitrogen reservoir, pressure regulators and relief valves for pressure demand feed of nitrogen, and tank pressure under climb and dive conditions. Nitrogen introduced into vent system or into fuel at bottom of tank. Use a heat exchanger to vaporize liquid nitrogen, or design system to accommodate droplets of liquid nitrogen.
Principle of Operation	Nitrogen is fed into tank and vent system to reduce oxygen concentration to levels which will not support combustion. The oxygen content is reduced by dilution, purging, or scrubbing.
Application Constraints	Use conventional vent and ullage pressure control valves and systems to enhance reliability. Design system (1) in accordance with MIL-P-5902, (2) to maintain a slight positive fuel tank pressure during all normal flight attitudes

TABLE XVIII - Continued

Application Constraints (Continued)	and conditions, (3) to minimize positive pressure and furnish excess nitrogen capacity to provide a given time of multi-hit capability with a given size battle damage perforation, (4) with capacity sufficient to maintain system inertness through mission altitude charges, (5) to be fail-safe so that system malfunction can develop negative tank pressures, (6) so that oxygen concentration in ullage and vent space is inerted when aircraft is in combat area, and (7) so that its function can be checked during preflight operations.
Performance	Excellent explosion and fire protection. Multihit capability limited by leakage of nitrogen through battle damage perforations, eventually exhausting nitrogen supply.
Weight	55 pounds LN_2; 75 pounds gaseous N_2 (for typical large helicopter)
Penalties	Logistics problems of LN_2. Preflight functional checks and servicing with nitrogen.
Availability	LN_2 available as by-product from LO_2 reduction. Quantity required may be a problem. Good availability for gaseous nitrogen supply.
Maintainability	Required maintenance is compatible with typical fuel and vent system periodical inspections.

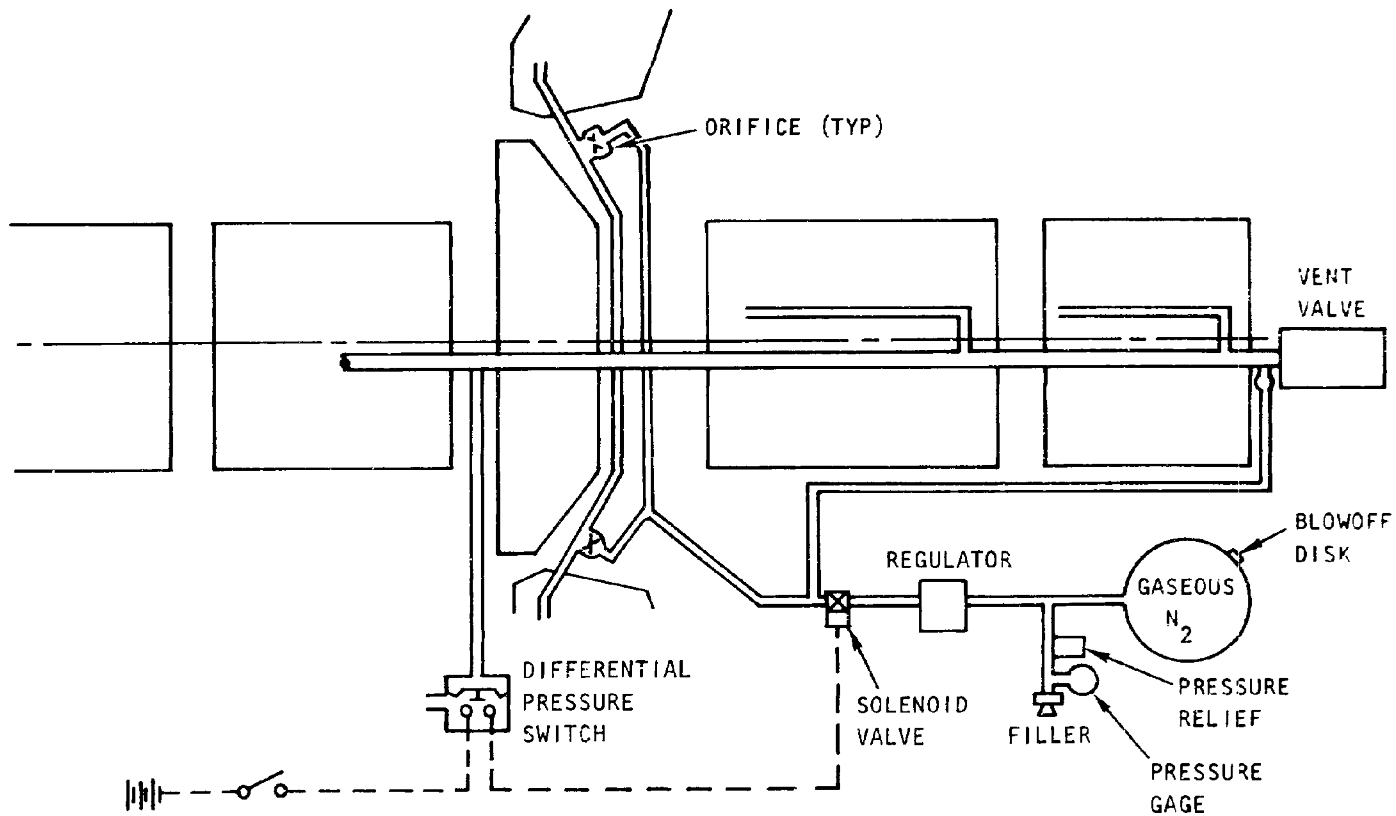


Figure 88. Schematic Diagram, Typical Gaseous Nitrogen Storage Inerting System.

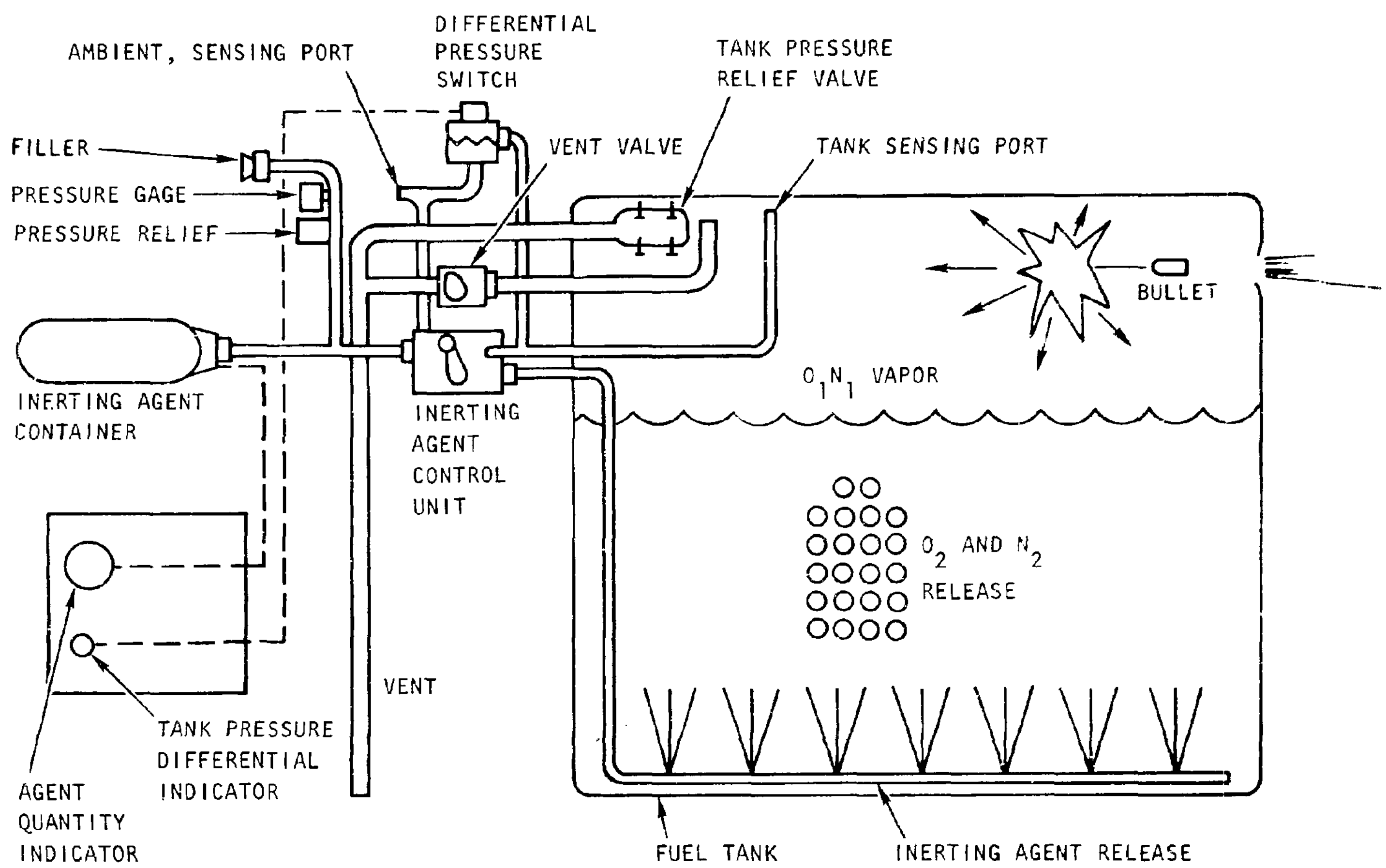


Figure 89. Schematic Diagram, Typical Gaseous Nitrogen Storage Inerting System, Deaerating Fuel Type.

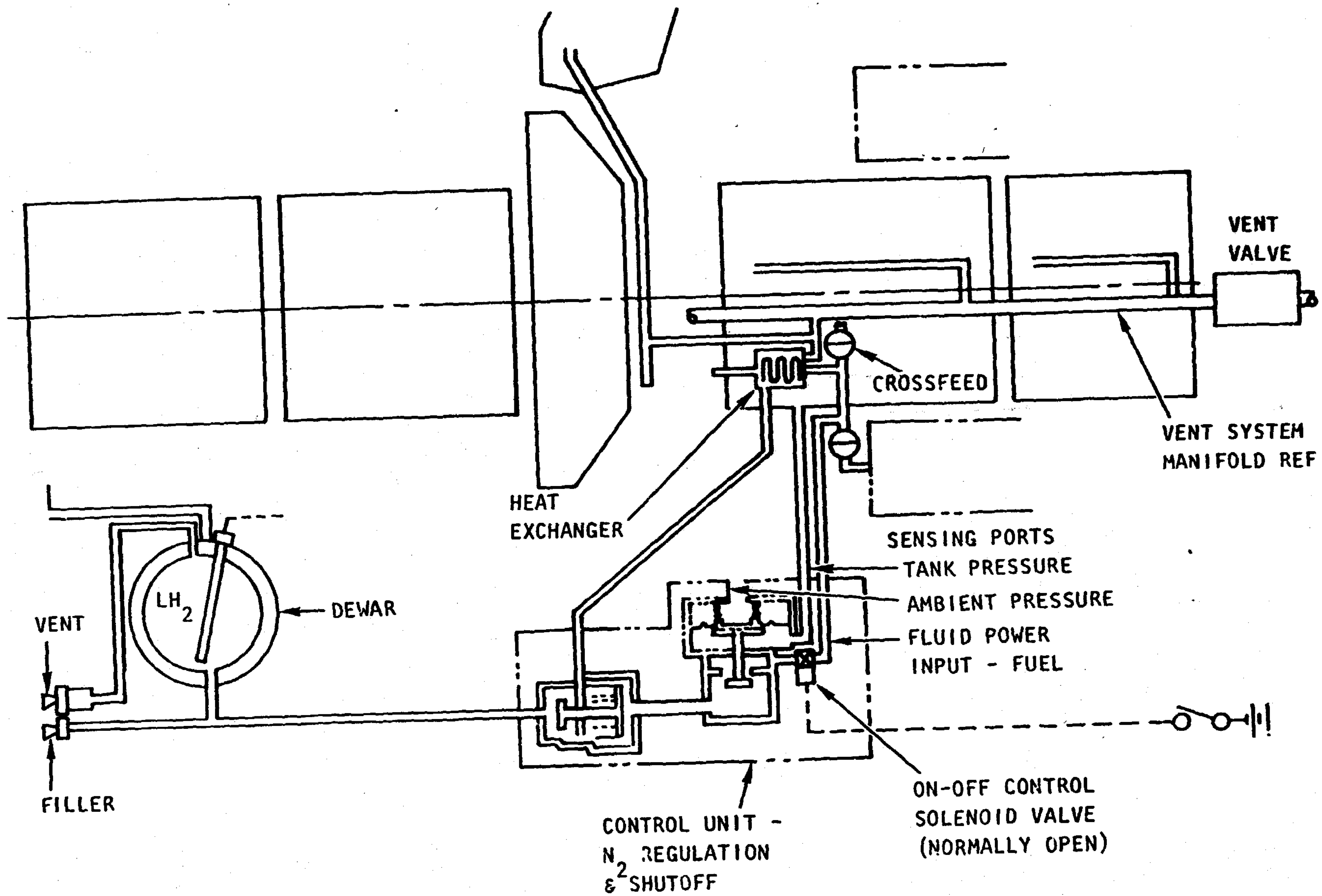


Figure 90. Schematic Diagram - Typical Liquid Nitrogen Storage Inerting System.

Engine exhaust gas is not considered an effective source of inerting gas. Under normal operating conditions, particularly in a glide or dive, turbine engine exhaust gas may contain a high proportion of oxygen. Accordingly, self-contained exhaust gas generators are necessary. These have a weight penalty in excess of the N_2 system. Table XIX contains data on generated inerting gas systems.[32]

TABLE XIX. DESCRIPTION OF GENERATED INERTING GAS

Function	Active: explosion proofing and fire prevention inside fuel tanks.
Configuration	Gas from fuel stoichiometric fuel-air ratio burner is cooled; condensed water, and corrosive and solid constituents are removed; and "conditioned" gas is routed to fuel tank ullage and vent spaces.
Principle of Operation	Conditioned gas, primarily carbon dioxide and nitrogen, dilutes oxygen concentration to levels below flammability limits.
Application Constraints	Space, fuel supply, and cooling requirements for gas generator and for gas conditioning and cleanup equipment present design problems. Corrosion is a major problem.
Performance	Satisfactory performance under service operating conditions has not been demonstrated.
Weight	Over 100 pounds for a medium-sized aircraft.
Availability	A satisfactory system is not known to be available.
Fuel Contamination	Fuel contamination is excessive if condensing, filtering, and conditioning elements are not carefully maintained.
Maintainability	A high level of preventive maintenance is necessary.

Catalytic inerting systems are under development. They catalytically absorb or combine with oxygen to reduce its proportion in the ullage. Low rate of absorption, water formation, catalyst contamination, and limited absorption capacity (requiring frequent catalyst replacement) are problems being studied.

4.5.4.2.3 Explosion Detector-Suppressor Systems: These systems provide microseconds response to suppress explosive combustion fronts. The two basic components of the system are an infrared radiation sensitive detector and an extinguishing capsule containing an explosive squib and fire extinguisher fluid.

The detector senses the radiation from an incipient explosion, fire, or the ignition source itself. The detector then acts as a switch, transmitting electrical energy to a detonator in the extinguishing capsule. The detonator explodes, breaking the capsule and scattering extinguishing agent through the explosion or fire, snuffing it out. An extremely fast response is required in order to limit the initial explosive combustion pressure to an acceptable level (2.5 psig). The detector has a visible and near-infrared radiation response covering the spectrum characteristics of both lean and rich mixture flames, as well as high-intensity sparks and flashes. Response generates a current signal into a low-impedance solid-state amplifier to discharge a capacitor through the extinguisher suppressor. Response time is 100 microseconds. A 250-cc suppressor of Freon FE 2402 will inert an unobstructed volume of 8 cubic feet in about 6 milliseconds. Rupture of the suppressor container shell is controlled by grooves, causing peeling action which prevents fragmentation by retaining the entire shell material.

Refer to Table XX and see Figure 91 for description and diagram of explosion detector-suppressor systems.[32]

4.5.4.3 Exterior Fire/Explosion Suppression: Fire and explosion suppression protective techniques may be used for the exterior of tank surfaces within the aircraft and in numerous aircraft spaces and compartments. The following techniques should be considered and evaluated:

a. Design spaces around tanks to be less than 1 inch thick to suppress flame propagation.

b. Seal spaces and compartments, and provide nitrogen inerting or detector suppressor/extinguishing systems.

c. Utilize sealed fire barriers and compartmentation to develop configurations for self-inertion.

TABLE XX. DESCRIPTION OF DETECTOR-SUPPRESSOR	
Function	Active: explosion/fire suppression and fire extinguishment in tanks, vents, and compartments.
Configuration	Infrared detector and a suppressor/extinguishing fluid container, dischargeable by initiator, both inside tank or compartment to be protected. System incorporates a current amplifier, power supply, test lamp, test switch, extinguishant discharge indicator, and necessary wiring and grounding. Detector may be either a single spot or dual "spaghetti" type tubular element which can be used to reduce line-of-sight problems in complex compartments.
Principle of Operation	Initial heat or flash excites detector which fires initiator explosively, distributing suppressor-extinguisher fluid. Fine spray of extinguisher fluid suppresses or extinguishes combustion before explosive pressures are generated or a fire can progress. Several sets of suppressors can be automatically fired in turn to extinguish persistent fires.
Application Constraints	System function must be checked during preflight operations. Locate detectors and suppressors in compartment so that each can "see" entire cavity. Provide access for inspection and maintenance of components.
Performance	Excellent. Explosion and fire protection.
Weight	90 pounds for typical large helicopter

TABLE XX - Continued

Penalties	System is complex, depends upon electrical continuity. It is sensitive to installation variations; close coordination with supplier during design and qualification is required.
Availability	Well-developed systems for both explosion suppression and extinguishing fires are available. Service experience with explosion suppression systems is limited.
Maintainability	Experience with these systems indicates electrical system maintenance problems. Preventive maintenance to prevent inadvertent firing and to insure reliability of detectors is necessary.

d. Provide high-velocity forced ventilation and streamlined airflow around self-sealing tanks, lines, and components where it would not cause a secondary fire hazard condition.

e. Position fire suppressant/extinguisher dispensers upstream in vent airflow.

f. Filling all spaces and voids where fuel liquid or vapor could collect and support combustion with:

1. Lightweight polyurethane plastic foam space filler, MIL-P-46111. Refer to Table XXI for description of reticulated polyurethane foam void filler.

2. Purge mats of rubberized fabric pressurized with nitrogen. (Refer to Table XXII and see Figure 92 for description and installation diagram.)[62]

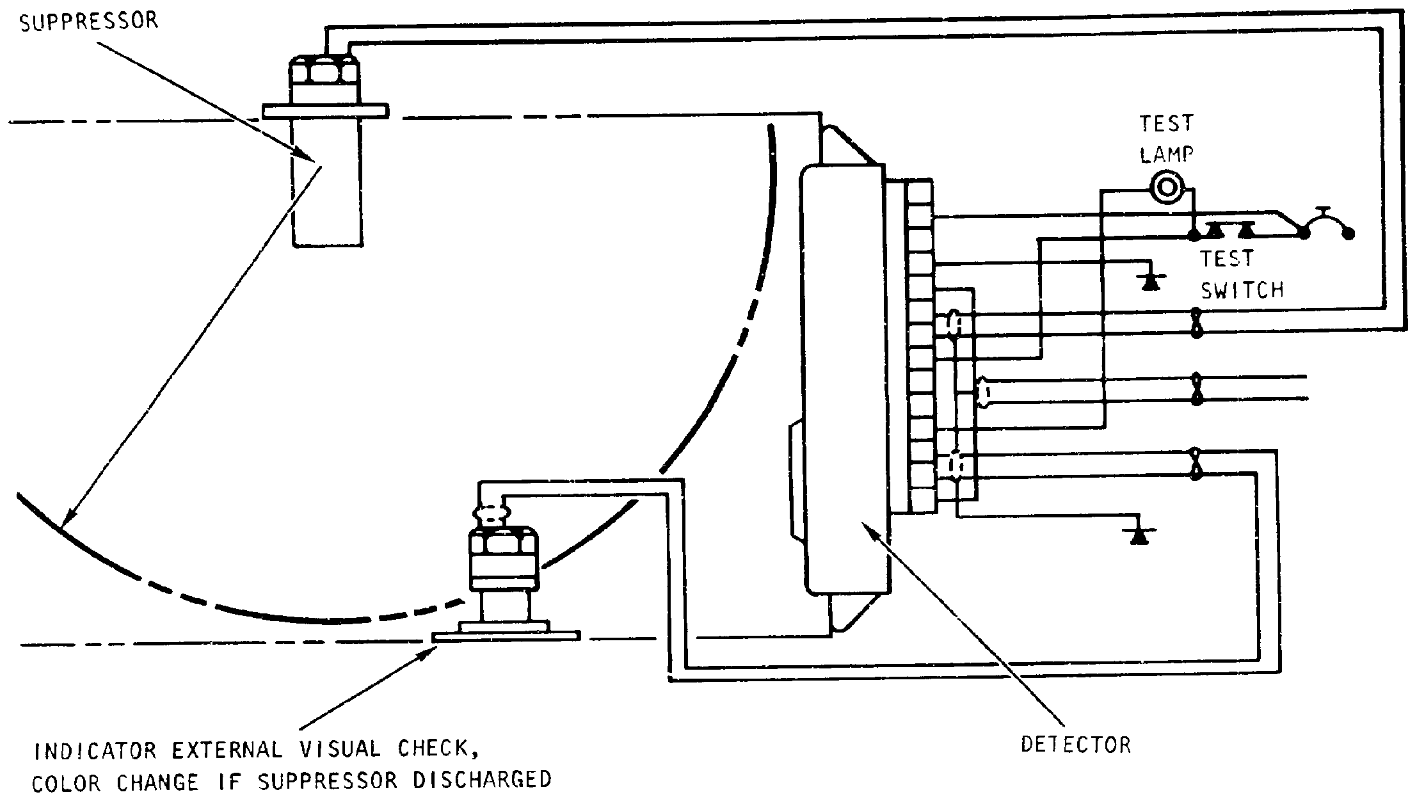


Figure 91. Schematic Diagram - Typical Fire and Explosion Detector Suppressor, Chemical Extinguishment.

TABLE XXI. DESCRIPTION OF PLASTIC FOAM, POLYURETHANE, MIL-P-46111	
Function	Passive: explosion proofing and fire prevention outside fuel tanks.
Configuration	Sponge-type polyurethane foam, 85 percent open pore, very soft.
Principle of Operation	Fills spaces and voids in airframe to keep ignition sources from fuel.
Performance	Excellent fire and explosion protection. Limits spread of existing fire.
Penalties	Weight. Tends to absorb liquid water and increase corrosion rate of structural parts not well-protected against corrosion. Installing blocks of foam in plastic bags with drain holes in bottom to drain condensation reduces water pickup. Design for use of plastic bags, or provide corrosion protection suitable for high corrosion rate environment.
Weight	1.5 pounds per cubic foot, dry.
Availability	Good. Supplied as blocks cut to size.
Maintainability	Some maintenance required. Periodic inspection for water or fuel pickup.

TABLE XXII. DESCRIPTION OF PURGE MATS	
Function	Passive: explosion proofing and fire prevention outside fuel tanks.
Configuration	Mats, pillows, or bags inflated with nitrogen. Nylon drop cords between surfaces serve to retain desired shape when mat is inflated.
Principle of Operation	Fills spaces and voids in aircraft, particularly around tanks and fuel-filled components, to deny oxygen to these areas, thus preventing fire from starting. When hit, purge mat inerts surrounding volume by release of nitrogen under pressure in mat.
Application Constraints	Requires close fit to aircraft voids, since nitrogen pressurization (50 psig) forces must not be applied to aircraft.
Performance	Very effective, even against high-energy incendiaries.
Penalties	Complexity of installation and maintenance, since mats sometimes must be mainfolded to nitrogen pressure source which is required to maintain continuous pressure.
Weight	Approximately 0.25 pound per square foot
Availability	Good custom design and fabrication required
Maintainability	Some maintenance required to maintain nitrogen pressure system and connections. Bags are very leak-resistant, but leakage location and repair may be required.

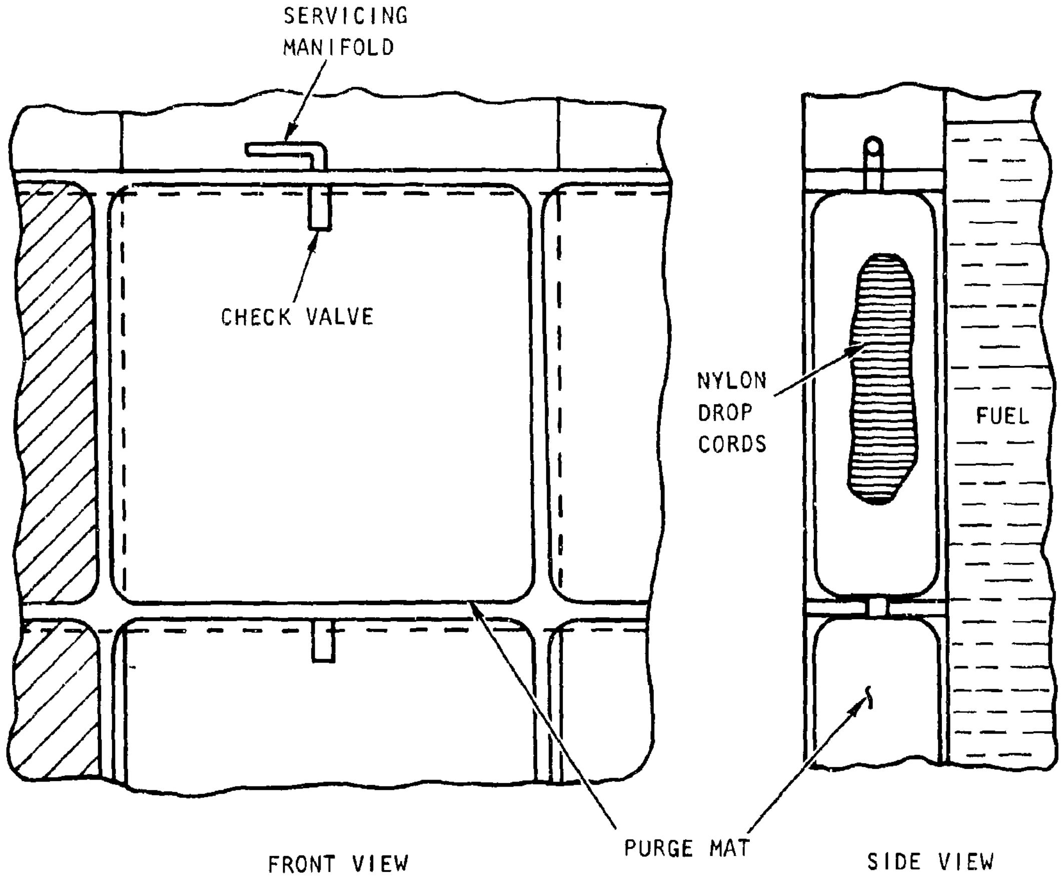


Figure 92. Typical Purge Mat Installation.

4.5.4.4 Lines and Hoses

4.5.4.4.1 Routings and Installation: Minimize potential leakage by:

- Minimizing number and length of lines and hoses which are external to fuel tanks

- Using self-sealing covers on critical lines which are external to tanks

- Using self-sealing hoses for exposed hose applications

- Applying damage-tolerance concepts to all lines not protected by self-sealing material

- Routing lines to avoid areas of spall from hits on adjacent structure and components

Minimize potential fire and explosion hazards by:

- Routing lines to avoid potential fire or ignition source areas

- Routing lines in areas which have fire and explosion protection

- Applying void filler foam (MIL-P-46111) to surround lines with layers at least 3 inches thick

- Applying self-inerting shrouds or quench packs with scuppers and overboard drains to all lines and hoses not otherwise protected from fire hazards

4.5.4.4.2 Material/Construction Selection: Minimize ballistic impact damage, suppress leakage, and increase damaged tolerance by selecting:

- Materials with high impact strength and high fracture toughness.

- Designs avoiding work-hardening embrittlement during fabrication, installation, and service.

- Couplings, connectors, and related elements designed to avoid stress concentrations and thin sections likely to fail catastrophically.

- Lines of filamentary composite materials, parallel laid and filament wound.

4.5.4.4.3 Self-Sealing Fuel Lines/Hoses: Liquid pressure pulse from interaction of ballistic penetrator with liquid fuel in the line can cause cracking, tearing, shattering, or petalling of the line walls. Liquid pressure pulse effects:

- Increase size of perforations and leakage
- Interfere with sealing function of the self-sealing material

Minimize leakage and maximize self-sealing effectiveness by:

- Line material/construction selection
- Application of self-sealing hoses, MIL-H-7061A, and self-sealing line covers

Table XXIII[61] contains a summary of self-sealing line cover materials and provides information on:

- Thickness
- Weight in pounds per foot of line
- Maximum sealing pressure after hits by .30- and .50-caliber AP M2 projectiles

4.5.4.4.4 Damage Tolerance: Maximize damage tolerance by:

a. Considering application of damage-limiting line wraps or filament windings of nylon, glass, and other filamentary composites with polyurethane, rubber, or epoxy matrices.

b. Reducing leakage rates of critical lines inside fuel tanks by application of polyurethane elastomer (Vithane-type) covers formulated to resist fuel immersion.

4.5.4.5 Components

4.5.4.5.1 Ballistic Defeat: Minimize weight for ballistic defeat protection of components by:

- Maximizing effectiveness of masking
- Applying armor protection techniques of Paragraph 3.10.3

TABLE XXIII. SELF-SEALING FUEL LINE COVERS

Manufacturer's Designation	Caliber and Velocity	Tube Material*	S/S Material OD (in.)	Weight (lb/ft)	Max Pressure (psi)
Goodyear FLC-4	.30 cal at 2,050 fps	6061-0 6061-T6	3.0 3.0	1.0 1.0	30 30
Firestone 1494		6061-0 6061-T6	3.0 3.0	1.3 1.3	20 20
1507		6061-T6	3.0	1.3	20
Uniroyal US190	.30 cal at 2,050 fps	6061-0 6061-T6	2.83 2.83	1.4 1.4	50 50
Firestone 1507	.50 cal at 2,425 fps	6061-0	3.0	1.21	15
Uniroyal US190	.50 cal at 2,425 fps	6061-T6	2.83	1.4	15

*Tube dimensions: 2-inch inside diameter, 0.049-inch wall thickness.

- Considering use of dual-hardness steel or 6Al-4V titanium annealed for component cases

4.5.4.5.2 Damage Tolerance: Maximize damage tolerance by:

- Designing for dual, redundant functional elements with minimum but adequate separation

- Applying damage-tolerance techniques to component cases to minimize failures

4.5.4.5.3 Material/Construction Selection: Maximize component protective effectiveness by:

- Selecting materials with high fracture toughness values.

- Using malleable, ductile materials and wrought, forged, or formed (instead of cast) component housings. Figure 93 shows more severe ballistic damage to cast than to wrought aluminum fuel component housings.

4.5.4.5.4 Self-Sealing Coverings: Minimize leakage, fire, and explosion by applying self-sealing covers to all critical fuel system components such as fuel lines, filters, and pumps. Many of the self-sealing line cover designations currently in use can be applied to component cases. Current self-sealing materials have the following nominal characteristics:

- Weight - 2 pounds per square foot

- Thickness - 0.375 inch

Self-sealing covers can be applied to component cases most effectively by high-temperature bonding, molding, and vulcanization processes conducted at the self-sealing equipment supplier's facility. Consult with self-sealing material and equipment suppliers for latest developmental and qualified self-sealing protection.

Consider leakage rate reduction for critical components inside tanks by application of polyurethane elastomer (Vithane-type) covers formulated to resist fuel immersion.

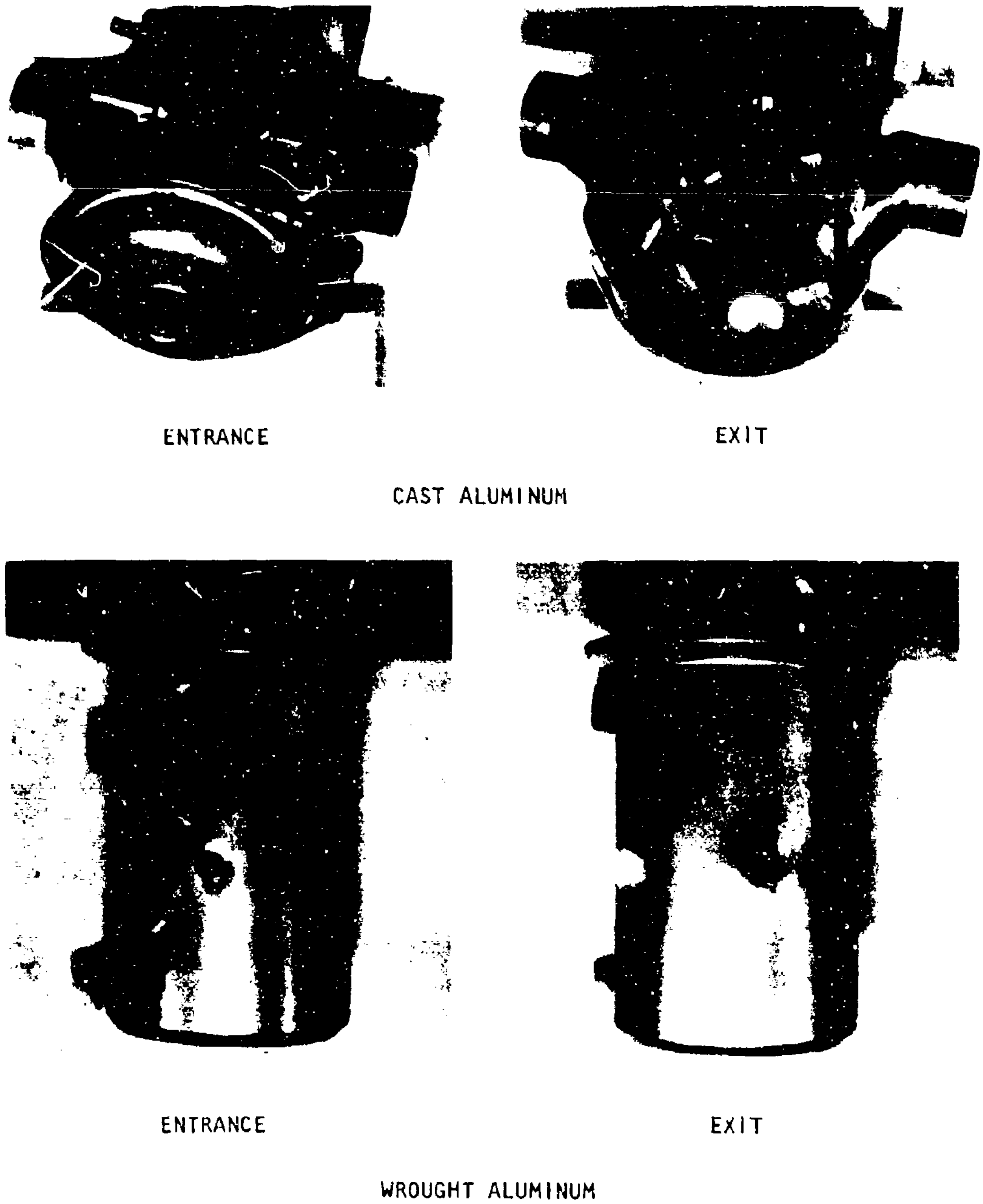


Figure 93. Comparison of Cast and Wrought Aluminum Fuel Component Ballistic Damage.

4.6 PROPULSION SYSTEMS

4.6.1 INTRODUCTION

Powerplant systems for rotary- and fixed-wing aircraft are basically similar in design and in their vulnerability to given levels of ballistic threats.

Protected, multiple engines can provide the greatest contribution to propulsion system survivability and a major reduction in aircraft losses from small-arms fire.

Consider, during early concept definition, multiple engines to maximize survivability and reliability.

Design multiple engine installations to provide:

- Single engine capability during portions of the flight envelope which are combat significant
- Separation and shielding to prevent fire, explosion, or catastrophic mechanical failure of one engine causing failure of another
- Redundant power transmission gearboxes
- Redundant and damage-tolerant power transmissions systems

There are two basic engine types: turbines and reciprocating (piston). Turbine engines, due to their power-to-weight ratios, are used almost exclusively for new aircraft designs in place of piston types.

A great deal of attention and research has been directed toward studying the vulnerability of existing turbine engines and enhancing survivability of future designs.[69-71]

General protective design techniques for propulsion systems are presented in the following paragraphs to provide the designer with candidate design features that may be applied to his specific system and installation.

4.6.2 BALLISTIC IMPACT EFFECTS

Application of protective design techniques to turbine engines, reciprocating engines, and propeller systems requires consideration of both primary and secondary ballistic effects.

Primary ballistic effects involve only the component or element hit and include:

- Perforation, distortion, tearing, cracking, rupturing, and shattering

- Ignition of combustibles by incendiary effects (i.e., incendiary projectiles or high-velocity fragments)

Secondary ballistic effects involve other components and systems in addition to the ones hit and include:

- Spallation, release of secondary fragments, and debris

- Release of flammable, burning, or corrosive fluids or gases.

- Failures or malfunctions of supporting subsystems

Examples of ballistic damage to turbine engines are shown in Figures 94, 95, and 96.

Figure 94 illustrates the damage sustained by a turbine engine compressor rotor assembly from a projectile impact. Note that the damage was confined to the last compressor-stage rotor and to the centrifugal impeller.

Figures 95 and 96 illustrate the damage sustained by the compressor section of a large turbine engine where the initial projectile impact damage, in the first-stage blades, cascaded and severely damaged the downstream stages. Note the complete removal of stator blades over nearly the entire section.

The consequences of primary and secondary ballistic damage effects on an aircraft's propulsion system must be evaluated systematically. To do this, a functional flow diagram of the system is useful in identifying those elements which are flight or mission critical.

Figure 97 illustrates the basic parts of a propulsion system and the interfaces with related subsystems whose integrity and/or operation is necessary. It traces a propulsion system's function from pilot input to engine power output.

- Throttle linkage - transmits pilot's requirements for engine power adjustment as input to the fuel control

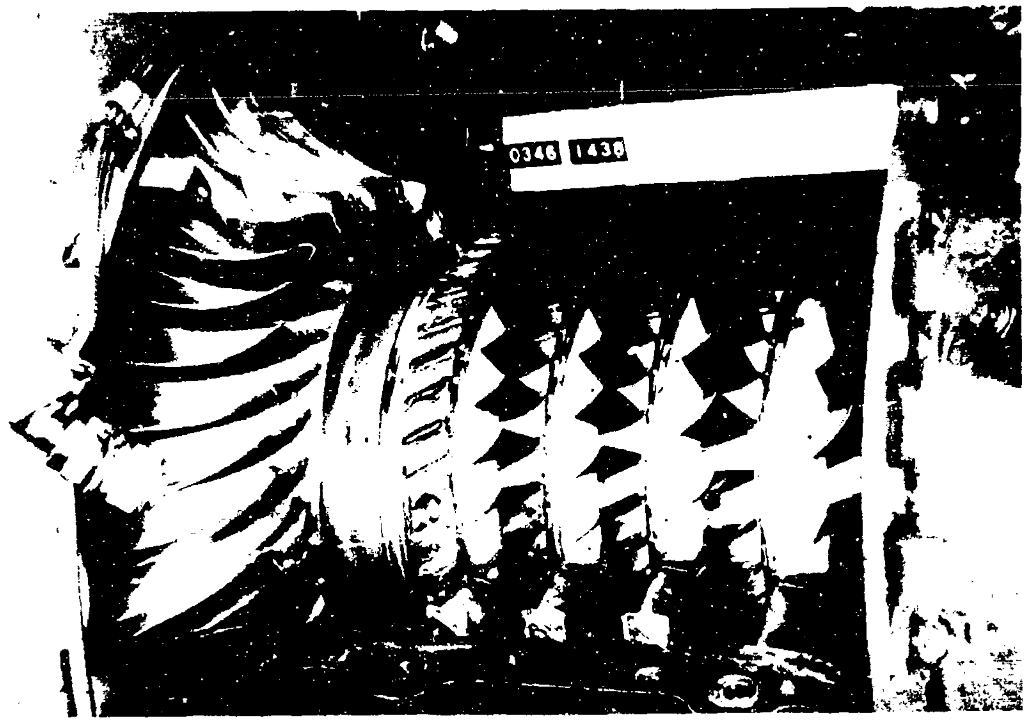


Figure 94. Last Compressor Stage Rotor and Centrifigal Impeller Damage.

- Fuel tanks - provide fuel feed to engine fuel control
- Engine fuel control - provides control of fuel feed to engine
- Lube supply - provides engine lubricating oil
- Engine - provides power output

4.6.3 TURBINE SYSTEM PROTECTION

Development of protective design techniques for turbine systems requires adequate consideration of primary and secondary ballistic effects. Highly stressed mission-critical parts rotating at high speeds in close relation

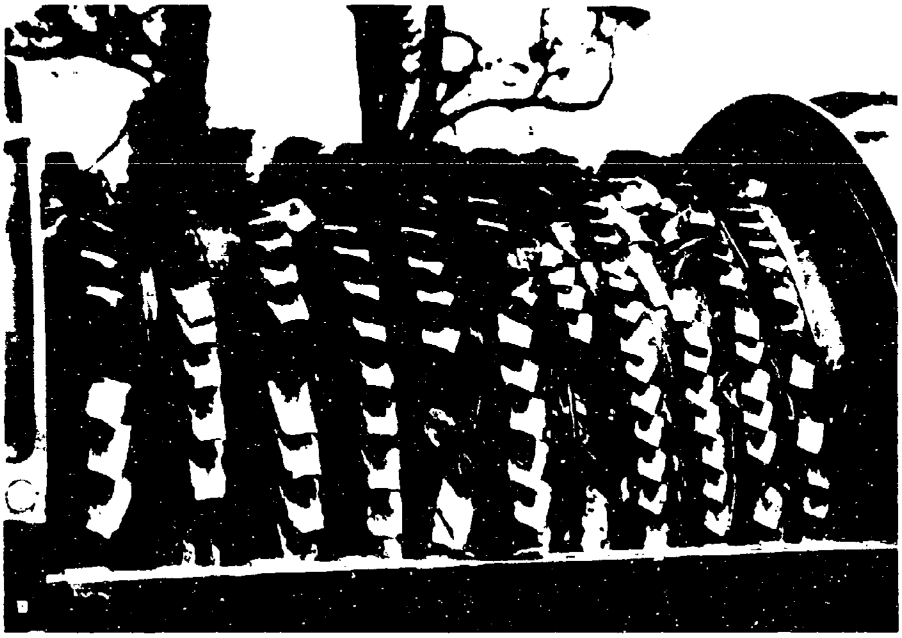


Figure 95. Compressor Section Damage.

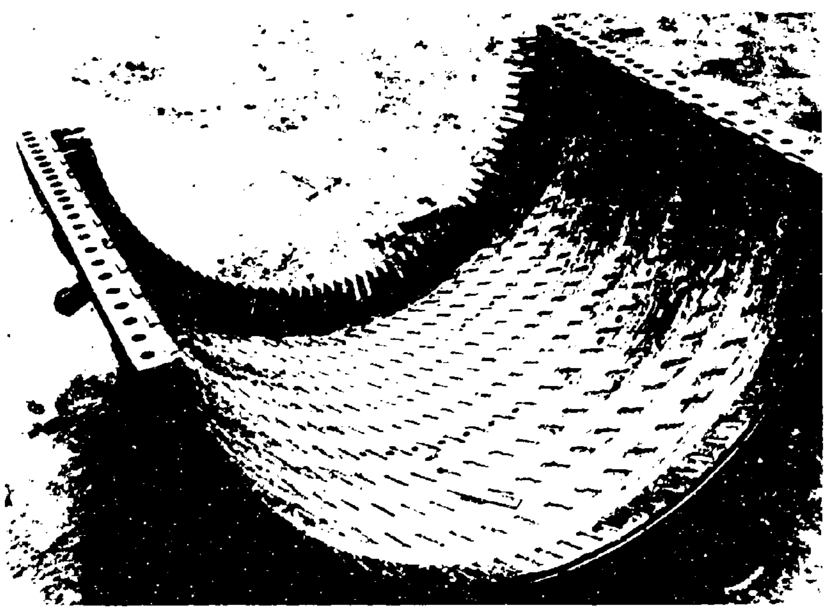


Figure 96. Stator Section Blade Damage.

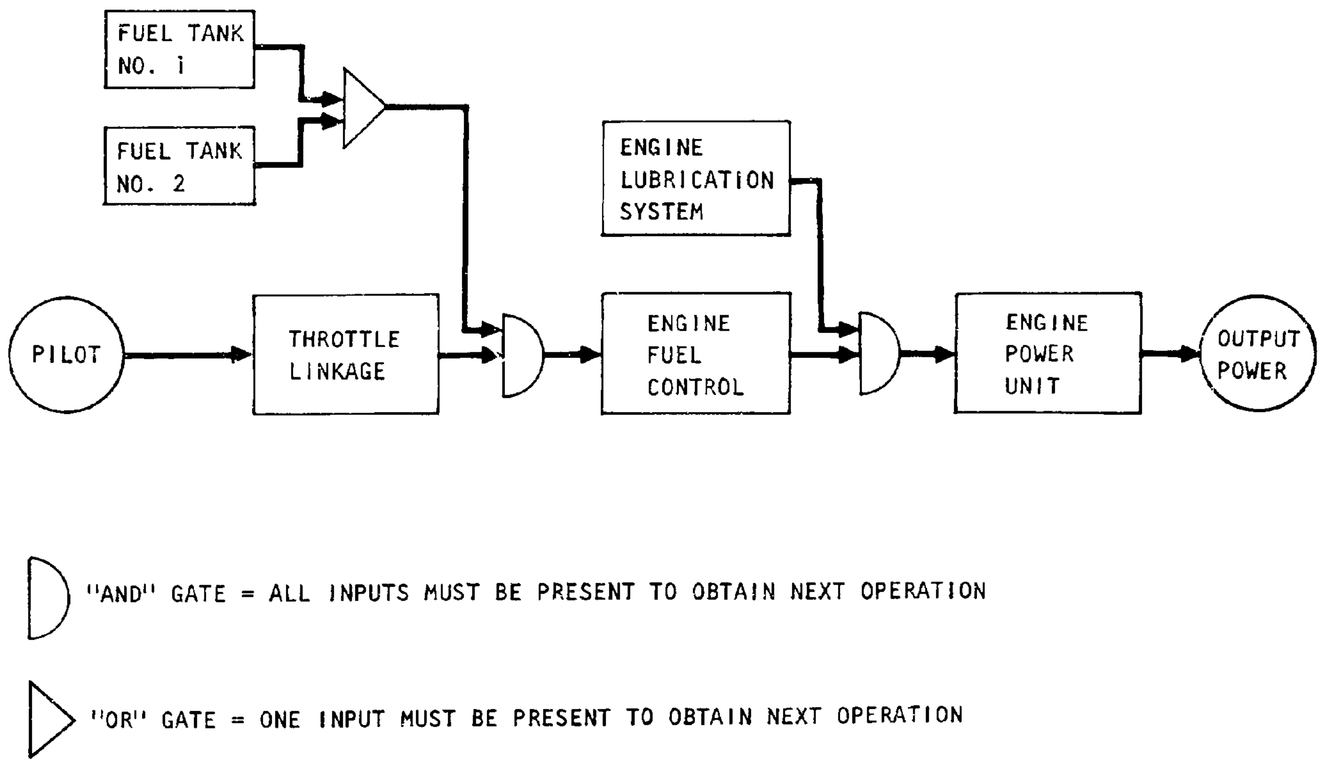


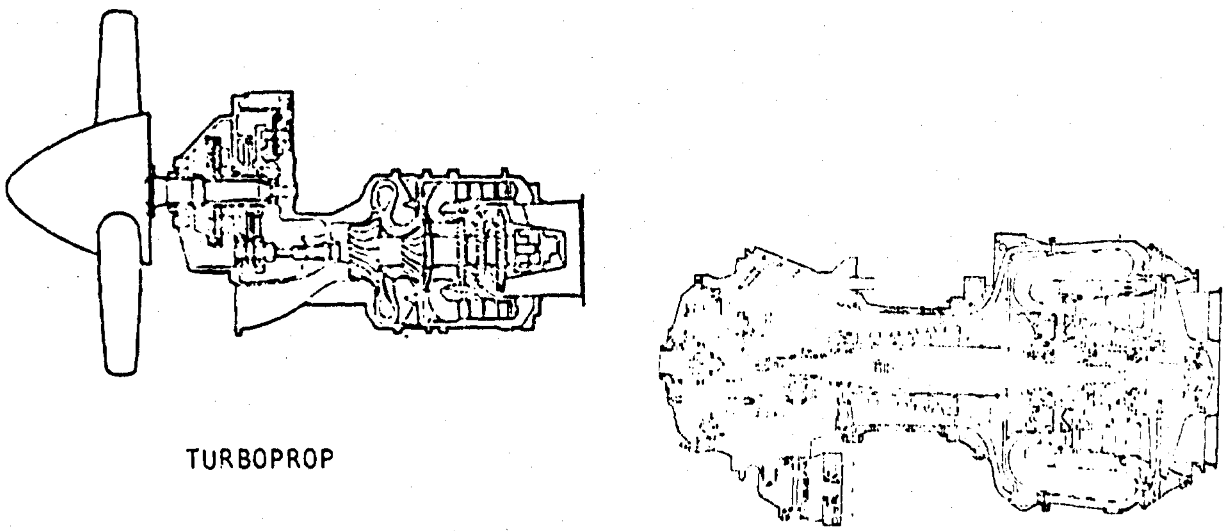
Figure 97. Propulsion System Functional Flow Diagram.

to other critical parts are extremely vulnerable. The probability of turbine system damage and failure modes' cascading to engine stoppage or catastrophic failure must be minimized by protective design techniques which relate ballistic effects to total system failure mode interactions. There are two types of turbine engines currently used for U.S. Army aircraft:

- Turboshaft
- Turboprop

Figure 98 shows typical examples of these engine types. They have several critical engine sections and systems in common:

- Compressor section
- Burner or combustion section
- Turbine section
- Fuel control system
- Lubrication system
- Output drive system



TURBOPROP

TURBOSHAFT

Figure 98. Army Aircraft Turbine Engine Types.

The output transmission drive systems for turboshafts and turboprops are presented in paragraph 4.7.

4.6.3.1 Engine Ballistic Resistance: Consider the use of integral and/or parasitic armor only after:

- All other protective design techniques to reduce vulnerability have been fully exploited
- The design configuration of the armor has been carefully adapted to miniaturization and concentration of the items being protected
- A cost/weight design trade-off study has been made for selection of the basic armor material and the armor installation
- The advantages of maximizing the proportion of the armor installation which can be installed and replaced in the field has been determined. These include:
  - Removal of armor from the aircraft for maximum aircraft performance and payload during long-range, training, and low-threat operations
  - Field replacement of damaged armor without repairing ballistic damage
  - Installation of higher threat-resistant armor for special missions

Conduct armor installation design trade-off studies to maximize installation merit rating from optimum combinations of the following:

- A separate shell of armor around the vulnerable components. Figure 99 shows an example of this concept.[72]
- Strategically placed armor pieces in areas of greatest sensitivity. Figure 100 shows an example of this technique on an existing aircraft.

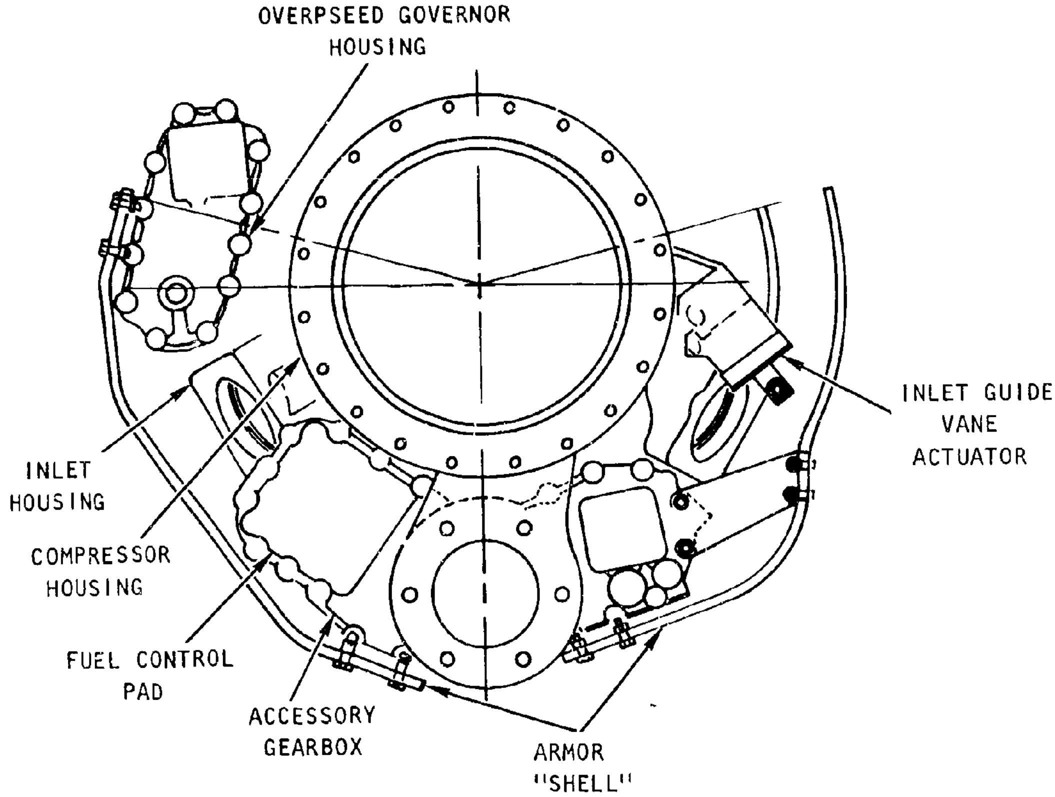


Figure 99. Engine "Shell" Armor.

4.6.3.2 Compressor Ballistic Resistance: Design compressor blades to minimize ballistic damage, secondary spalling, and foreign object damage, considering the following techniques:

- Use hollow blades and vanes of low aspect ratio to minimize size of pieces broken off by impact.
- Avoid cast blades and vanes, since they have greater tendency to shatter, breaking into larger, more lethal pieces when hit.
- Minimize number of rotor blades to reduce probability of multiple blade damage from a single hit.
- Avoid sections so thin that they are fragile.

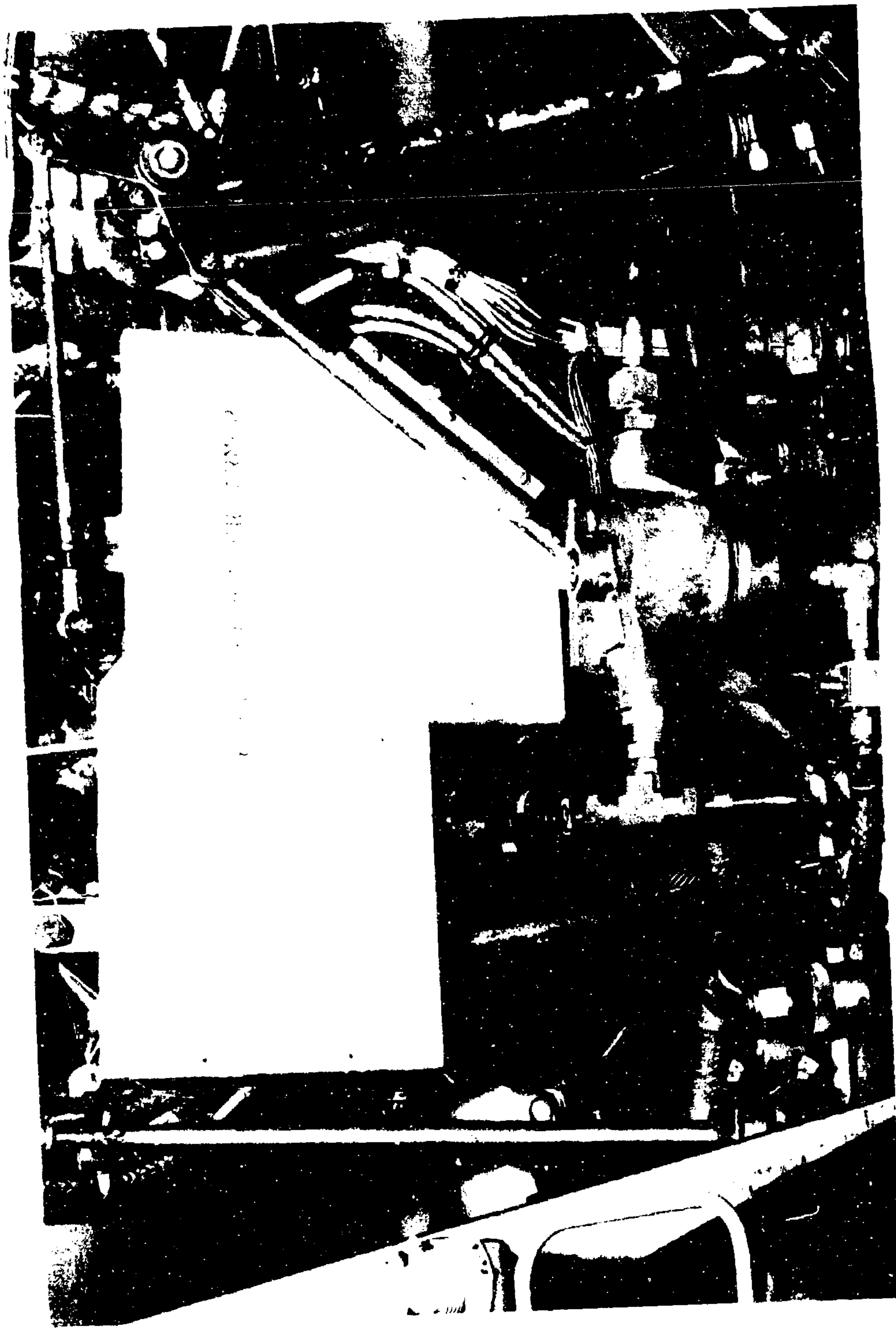


Figure 100. Armor in Areas of Greatest Sensitivity.

- Design compressor stators with inner and outer shrouds designed for positive security of vane ends. Avoid assembling with rivets in gas path.
- Maximize blade and vane spacing to minimize multiple damage break-off of adjacent blades and vanes.
- Maximize diametral and other clearances to increase damage tolerance to interferences caused by foreign objects and debris broken from rotating components.
- Avoid variable-geometry stators, unless their design incorporates vane-end securance equivalent to a rugged fixed-vane design, and vane actuation does not add to the vulnerability by including exposed fuel lines and actuators.
- Use tough, high-strength steel for rotor discs to minimize breakup from impacts.
- Sensitivity to blade and vane chipping must be minimized by providing sufficient stall margin.
- Provide rugged rotor bearings and bearing supports. Provide bearings of tough material, case hardened or carborized for wear, to withstand out-of-balance conditions and ballistic impact.
- Provide rotor bearings with maximum time-to-die capability after loss of lubrication.
- Provide rugged rotor attachments, retainer clip pins, rivets, etc., to minimize fore and aft movement from projectile impact forces.
- For maximum hardening, consider armor protection of compressor section. Refer to Paragraph 3.10.3 for armor and armor installation information.
- Maximize ballistic merit rating of armor installation by selecting optimum armor for compressor section from armor systems, including:
  - Integral compressor case/armor
  - Separate shell of armor around compressor case
  - Spaced armor concepts using combinations of integral and shell armor plus aircraft mold line material designed for ballistic protective effectiveness to tip, tumble, and break up projectiles and fragements.
- Consider developmental composite materials (e.g., carbon, boron, and glass fiber-reinforced materials) for compressor housing, stator vanes, and rotor blades.

4.6.3.3 Turbine Ballistic Resistance: Apply to turbine sections the same protective design techniques presented in paragraph 4.6.3.2 for the compressor. This includes the radial-type rotor, which is also favored to minimize turbine vulnerability.

Certain exceptions to compressor protective design are applicable to turbines. These include:

- Use of unshrouded rotor blades with compensation for lack of shroud support by using:
  - Widely spaced, low-aspect-ratio blades
  - Extra-rugged disc mounting with materials tough at high temperatures
- Use of ductile blade material that resists fracturing at high temperatures and will perforate without shattering into chunks
- Incorporate nozzles with inner and outer rings designed so that vanes are fully welded or securely fastened at both ends to prevent fallout of vane when broken in two
- Design of the vanes to have:
  - Hollow, thin, cross sections
  - Very ductile material which will perforate without chunking
- Strengthen turbine rotor supports to withstand a high degree of unbalance
- For maximum hardening, considerations of armor protection of the turbine section. (Refer to Paragraph 3.10.3 for armor and armor installation information.)

4.6.3.4 Burner Ballistic Resistance: Design burner sections and fuel injector components to minimize presented area in principal threat aspects not masked by other components or engine sections.

Select burner materials that are tough at high operating temperatures to provide:

- Maximum fracture toughness for all portions of the burner
- High ductility for burner shell to minimize hole size and torching after perforation

Design burner configuration to:

- Minimize stress concentrations at operating temperature
- Limit cracking
- Remain structurally sound after a hit

Avoid installing the engine such that burner torching can cause critical damage. Also, avoid running flammable fluid plumbing within reach of such effects.

Protect components and critical structure adjacent to burners from damage and failure because torching from perforated burners by applying:

- High-temperature-resistant materials to adjacent components
- Interposing flame-resistant heat barriers

4.6.3.5 Lubrication System Ballistic Resistance: One of the more important items for the reduction of overall engine vulnerability is a fail-safe lubrication system. Vulnerability of this system is caused by:

a. The relatively large presented areas of:

(1) The lube oil tank, pump, filter, and oil cooler

(2) The engine oil and accessory gearbox sump

(3) Oil lines, hoses, and valves

b. The ease of perforation of lube oil system components and elements by relatively small projectiles, fragments, and spall.

c. The very little time the pilot has to act after loss of oil pressure and the serious hazards that result.

Protective design techniques for lubricating oil systems follow. Examples of related damage and failure modes are also presented.

Figure 101 shows the damage to an engine oil tank from a projectile impact. Note the extent of damage caused by hydraulic ram effect.

Figure 102 shows an example of an engine main shaft bearing failure caused by loss of lubrication.

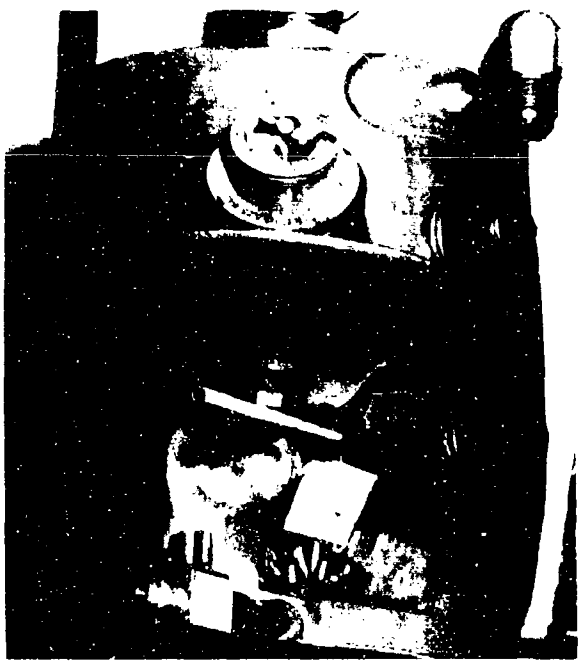


Figure 101. Engine Oil Tank Damaged by Projectile Impact.

Figure 102. Mainshaft Bearing Failure Caused by Loss of Lubrication.

Design for longer time to die after lubrication loss by:

- Use of bearings with high heat tolerance.
- Coating of bearings with dry film lubricant to extend time to failure under poor lubrication conditions.
- Consideration of lubricating oil additives and advanced-type synthetic lubricants to improve lubricating qualities of lubricant remaining in bearing after oil pressure is lost.
- Providing for manual override by pilot to prevent automatic shutdown of engine after loss of oil pressure and to permit escape from immediate combat area.
- Consideration of bypass systems to isolate engine oil circulation from damaged and leaking portions of oil circulation system, such as system developed for UH-1, shown in Figure 103.

Design oil sumps within engines to have internal pump capability (e.g., ejector-type) for emergency operation.

Configure oil strainers and magnetic plugs to prevent ballistic damage debris from entering oil pump or bearing jets without causing a blockage of oil flow.

Locate oil cooler on, or as close to, engine as practical on side away from expected ballistic threats. When possible, do not add to fuel system vulnerable area by using fuel as a coolant for oil.

Locate oil lines so as to minimize exposed area, as follows:

- Pressure and scavenge lines in protected area on top of engine
- Vertical and radial lines buried within engine if practicable

Minimize oil line leakage by:

- Minimizing length of lines, particularly exposed lines
- Applying self-sealing and fire-resistant techniques. For caliber .30 and .50 ball projectile hits, puncture leakage for lines over .75 inch diameter can be reduced 90 percent or more by applying self-sealing hose for tubing or standard flexible hose.

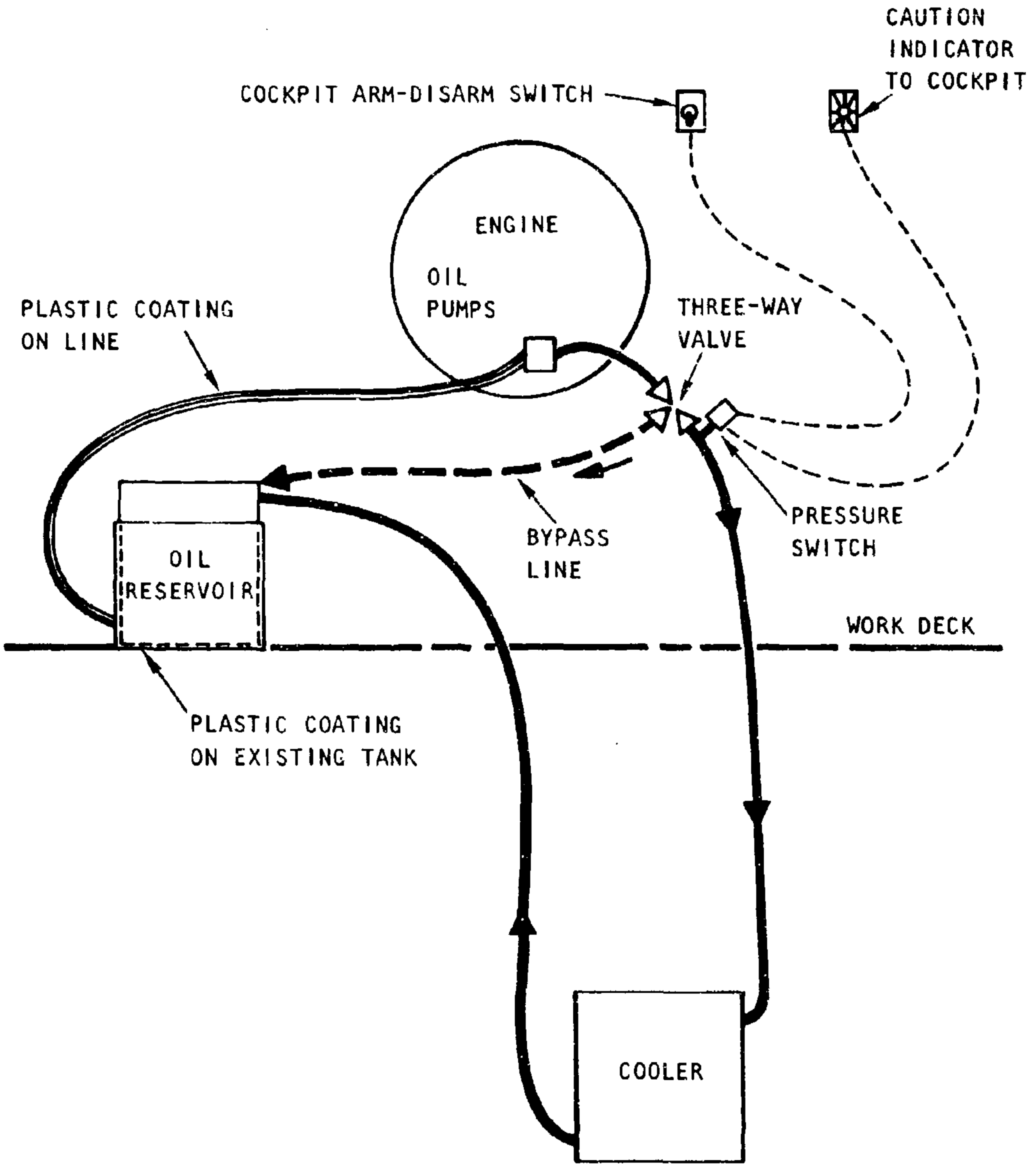


Figure 103. UH-1 Engine Oil System Oil Cooler Bypass Modification.

Minimize oil leakage from oil reservoirs, oil sumps, and other oil system components by:

- Miniaturizing components and burying them in larger components, reservoirs, and sumps

- Applying self-sealing covers

Design self-sealing applications for easy replacement in the field. Exposure to oil operating temperatures for extended periods of time causes degradation of the self-sealing material, and reduces its sealing effectiveness. However, even age-hardened self-sealing material provides substantial reductions in leakage, compared to the standard oil tank materials currently used.

Consider ballistic-resistant materials for walls of tanks and components. These materials include:

- Fibrous composites (e.g., glass, boron, carbon)

- Armor heavy enough to defeat threat without spalling damage to system

4.6.3.6 Fuel Control System Ballistic Resistance: The engine fuel system ranks with engine lubrication as one of the important considerations in the reduction of engine vulnerability. The fuel system is "soft" for many of the same reasons as for the lubrication system. Defeat of the engine fuel system will usually cause a decay or loss of power and a certainty of fuel leakage accompanied by a high probability of catostrophic fire.

Maximize engine fuel system ballistic resistance by designing:

- Fuel control linkages with large-diameter tubing and large rod ends and bellcranks having structurally redundant, damage-tolerant sections. (Refer to paragraphs on flight control system for design techniques.)

- Fuel control and other elements of engine power controls to fail-safe predetermined positions if pilot-operated or automatic controls fail

- Miniaturized fuel pumps, controls, and other components to:

  - Reduce presented areas

  - Reduce armor penalties

  - Aid in masking or burying

- Installation of fuel pumps, controls, and other components to be buried within engine housings. An example, Figure 104, is the evolution of burying to improve masking of a miniaturized fuel pump/control for a research engine.

- Fuel lines of minimum length, buried whenever feasible. Vulnerability was reduced in one engine by routing the main fuel supply line through the center shaft to the fuel slinger manifold as shown in Figure 105.

- Sandwich or piggyback construction techniques to integrate or cluster vulnerable lines, components, and circuits into small packages.

- Fail-safe or manual override provisions for control of pressure transducers, temperature probes, and fuel control valves in case of automatic system failures which could interfere with engine function.

- Valves with large clearances to avoid hang-up from ballistic distortion.

- Turbine overtemperature protection in fuel control to allow substantial operation of a lower power output after damage to compressor, without automatically producing fuel-rich mixtures which quickly burn out the turbine section.

- Simple, fail-safe computer and control concepts (e.g., fluidics) to minimize engine vulnerability.

- To avoid use of armor which would cause spall damage to soft components.

Minimize potential engine fuel system leakage by designing:

- Fuel nozzles using minimum practical fuel pressures.

- Main shaft fuel slinger for fuel manifold supply to eliminate the need for high-pressure engine fuel lines.

- Fuel system components and bodies of high-strength, high-fracture toughness materials, including consideration of filamentary composites.

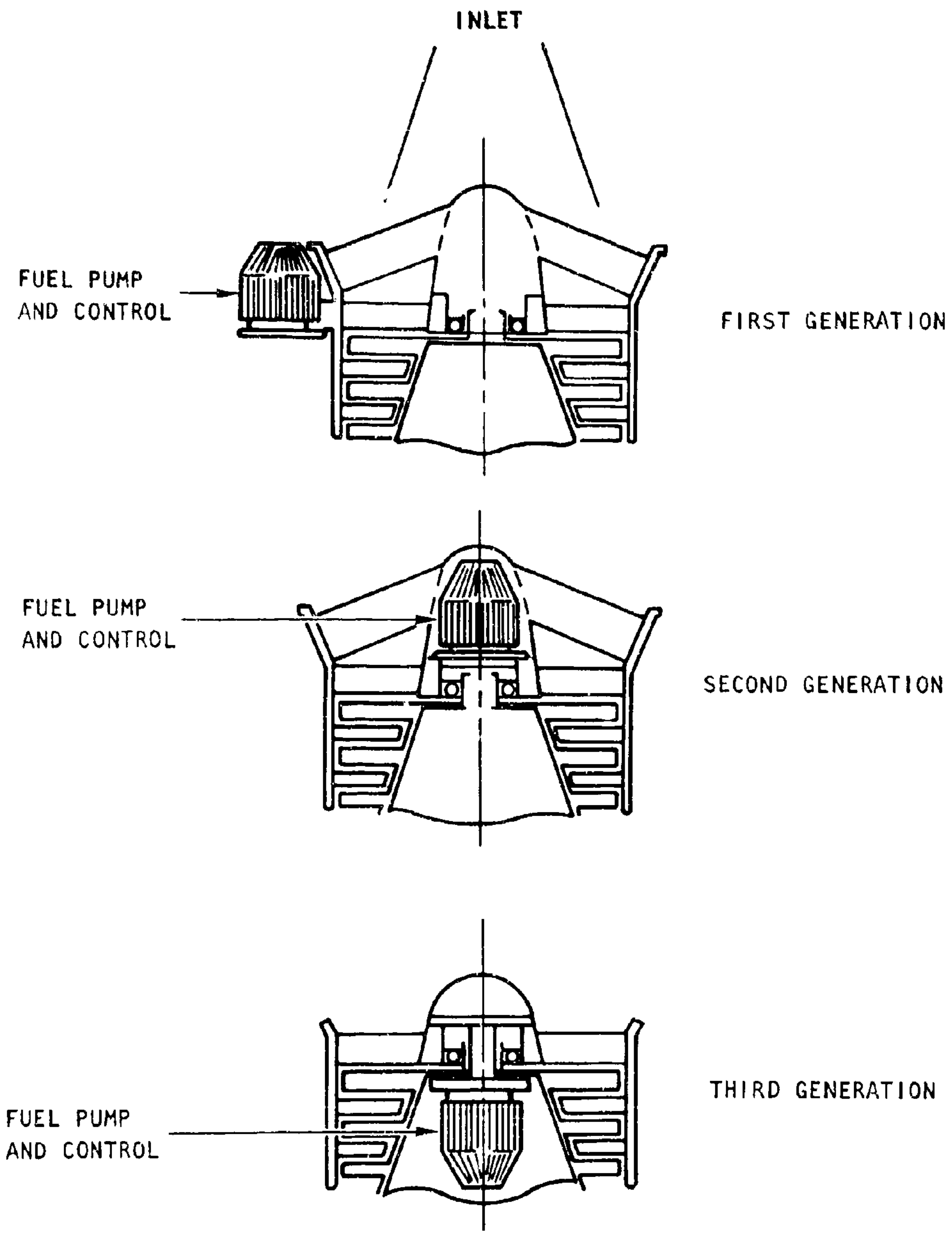


Figure 104. Engine Fuel System Component Masking Development.

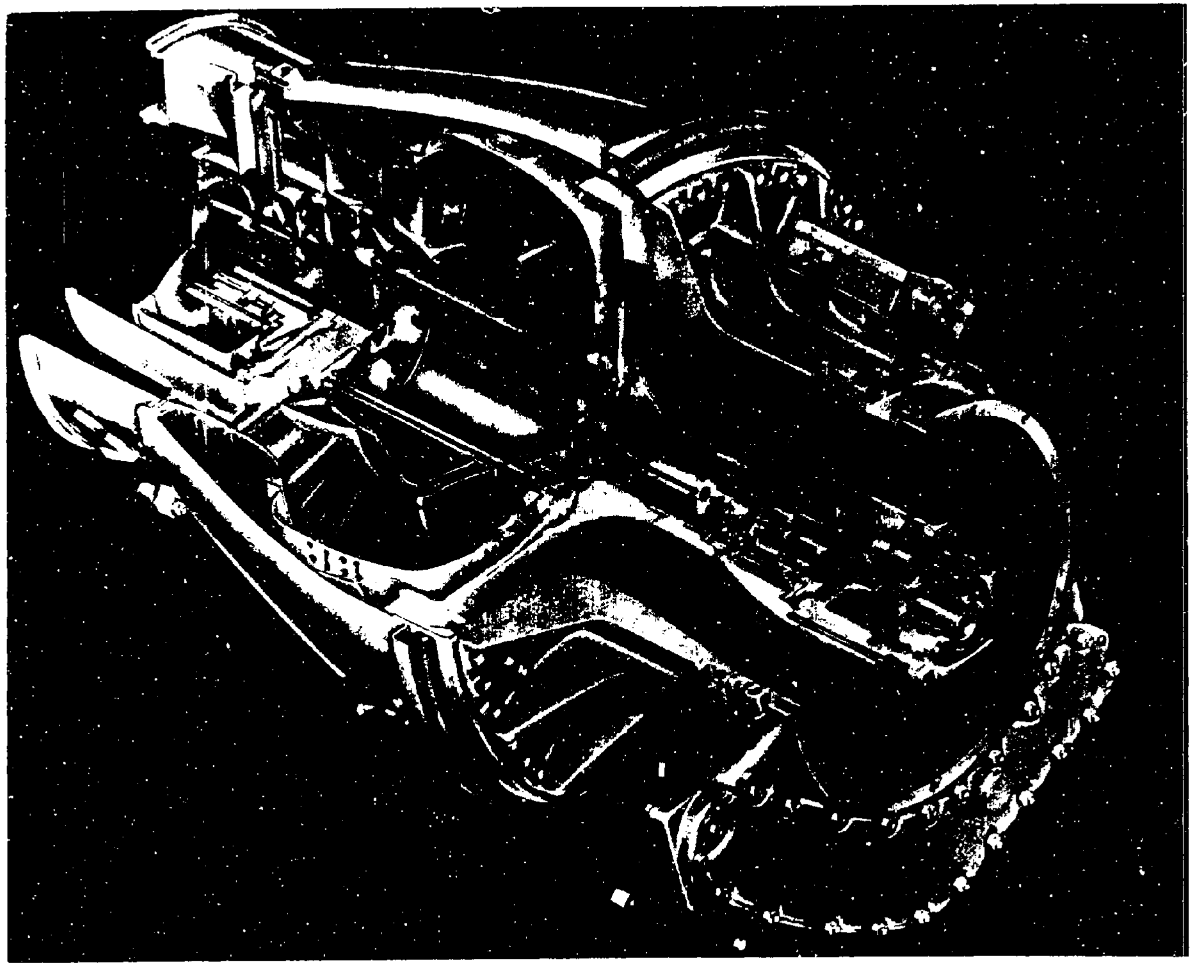


Figure 105. Main Fuel Supply Line Routed Through Center Shaft to Fuel Slinger.

- All exposed components with self-sealing covers (MIL-H-7061 self-sealing hose for flexible fuel lines).

- Self-sealing applications for field installation and considerations for replacement after hardening because of time and temperature.

4.6.3.7 Engine Inlets: Particular attention must be directed to the design of turbine engine inlets to minimize the effect of small-arms fire on the engine. Inlets should be constructed of materials and structural designs such that ballistic penetration will not cause secondary fragmentation or debris to be generated that would be capable of causing foreign object damage (FOD) to the engine. Low-density sandwich construction should be considered to avoid the use of metallic fasteners that could be disloged by impact of a projectile and injested in the engine. Avoid assembly with rivets in the airstream.

4.6.3.8 Fire/Explosion Suppression: Apply the basic principles and protective devices of Section 3 to fire and explosion suppression in engine installation.

Review provisions for flammable fluid leakage suppression and control, given in Section 4, to reduce the magnitude of the fire suppression problem.

Apply fire/explosion suppression techniques to engine installation, considering unique characteristics of engine environment, including:

- High temperatures

- Necessity for fire resistance and fireproofing

- Engine compartment ventilation flow rates

- Continual collection and absorption of flammable engine fluids in porous materials.

Emphasize fire/explosion suppression techniques that are particularly useful for the engine compartment. These include:

- High-velocity ventilation and forced, high-rate drainage of potential hazardous leakage areas.

- Low-velocity ventilation and fire/explosion detector/suppressors and/or fire extinguishers. A "second shot" of fire extinguisher action should be available to the crew.

- Automatic and crew override controlled fuel, lube, and hydraulic fluid shutoff valves to stop flow of flammables until fire extinguishers can put out the fire
- Shielded and sealed electrical and other ignition sources
- Quench packs (foam in enclosure) around ignition sources
- Quench packs with scupper drains shrouding potential leakage sources
- MIL-P-4611 plastic foam space filler in plastic film envelopes installed in areas where flammable liquids or vapors could collect but which are not practical to drain and ventilate

4.6.4 RECIPROCATING ENGINE SYSTEMS

Reciprocating engines are less vulnerable than turbine engine to small-arms fire and cascading failure modes.

Their use is limited in Army aircraft due to the nearly exclusive use and development of the turbine engine. The following are basic principles that should be considered where piston engines are used.

4.6.4.1 Fuel Controls/Pumps: Locate carburetors behind the engine, with as much shielding from cylinders and the engine casing as practicable.

Shield fuel supply line and provide self-sealing capability.

Design fuel pumps and governor independent of vulnerable power sources (i.e., engine oil pressure).

4.6.4.2 Accessories: Locate distributors and magnetos on aft side of engine for maximum shielding.

Provide maximum separation of dual ignition system elements.

4.6.4.3 Lubrication: Consider the same protective design techniques presented for turbine engine lubricating oil systems.

4.6.5 PROPELLER SYSTEMS

For propeller blades, gearbox housing, and pitch controls:

- Select material to provide maximum toughness and fracture resistance.
- Design component configurations to minimize crack propagation.
- Design all elements for high damage tolerance capability.
- Design for maximum resistance to dynamic forces from out-of-balance operation.

4.6.5.1 Propeller

- Design the propeller with a strong structural box core to minimize blade throwing after impact.
- Consider steel spar-fiber glass structural composite blade propeller.

4.6.5.2 Gearbox: Apply protective design techniques presented for gearboxes, accessory cases, and power transmission systems in Section 4.7.

4.6.5.3 Pitch Control: Apply protective design techniques for accessory and gearbox cases to the pitch control.

Design pitch control for fail-safe blade angle positioning.

Integrate the propeller control with the gearbox in a position to obtain the most beneficial natural "masking" of the sensitive components.

4.6.5.4 Armor Protection: Consider the use of armor for those critical areas that are not protected by techniques previously described.

4.7 POWER TRAIN SYSTEMS

4.7.1 INTRODUCTION

Power train systems carry primary responsibility for flight capability in all Army rotary-wing aircraft and for those propeller-driven fixed-wing aircraft dependent upon speed reduction gearboxes. A variety of main rotor drive system configurations have evolved over the past 20 years of helicopter development. Each system consists of a series of transmissions or

gearboxes and connecting drive shafts to transmit power from the engine(s) to rotor blades. The need for antitorque thrust capability in single-rotor helicopters creates a requirement for an additional drive system.

Figure 106 shows a schematic diagram of the drive system of the UH-1 helicopter, which is reasonably typical of turboshaft-powered, single-engine, single-main rotor helicopters. The high output speed ($\approx$20,000 rpm) from the power turbine is first reduced within the engine to about 6,000 rpm. It is then transmitted to the main transmission, where the speed is further reduced through a set of spiral bevel gears and two stages of planetary gears, finally providing a main rotor speed of 324 rpm. The trend in helicopter drive systems is toward incorporation of all speed reduction in one transmission to reduce overall weight and complexity.

Most twin-engine (turboshaft) driven helicopters have direct drive from a high-speed power turbine to intermediate transmissions or to a main rotor transmission. Figure 107 shows a schematic of the CH-47 medium transport helicopter, with the major power train system components identified. The engine power turbine output speed ($\approx$15,400 rpm) to the engine transmission is reduced to 12,200 rpm through a set of bevel gears, and further reduced in the combined transmission bevel gears to 7,050 rpm and directed through interconnecting shafts to the forward and aft transmissions. A third set of bevel gears in each main rotor transmission reduces speed to 4,000 rpm; finally, reduction through two stages of planetary gears provides a main rotor speed of 230 rpm. The main transmission performs many other functions in addition to speed reduction and transmission of primary power; e.g., output drives for tail rotors, hydraulic pumps, and generators often originate from the main transmission.

The following paragraphs discuss the ballistic damage effects and the detailed design considerations that may be used to achieve the best combinations of survivability features for application to drive systems.

4.7.2 BALLISTIC DAMAGE EFFECTS

Power train systems exposed to small-arms fire have two general failure mechanisms: (1) direct projectile damage to critical dynamic components such as bearings, gears, and shafts, and (2) loss of lubrication, usually caused by perforation of oil containing components. Loss of lubrication is the predominate failure mode for existing transmissions and gearboxes in a small-arms threat environment.[77]

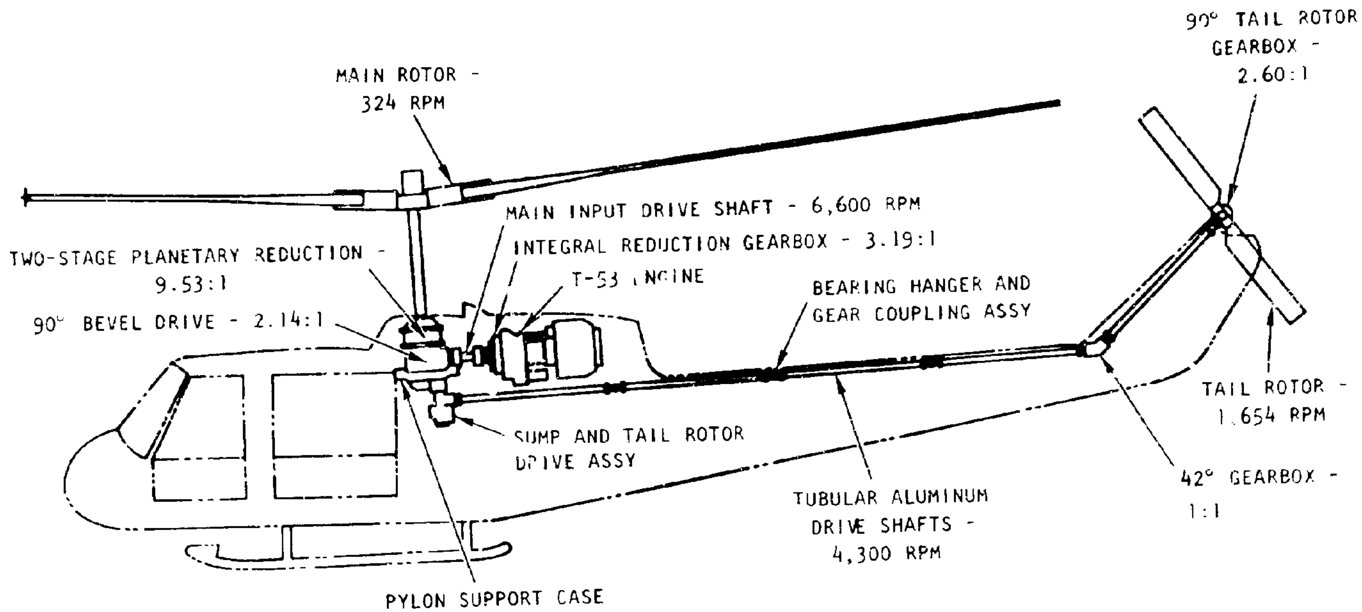


Figure 106. UH-1 Power Transmission System.

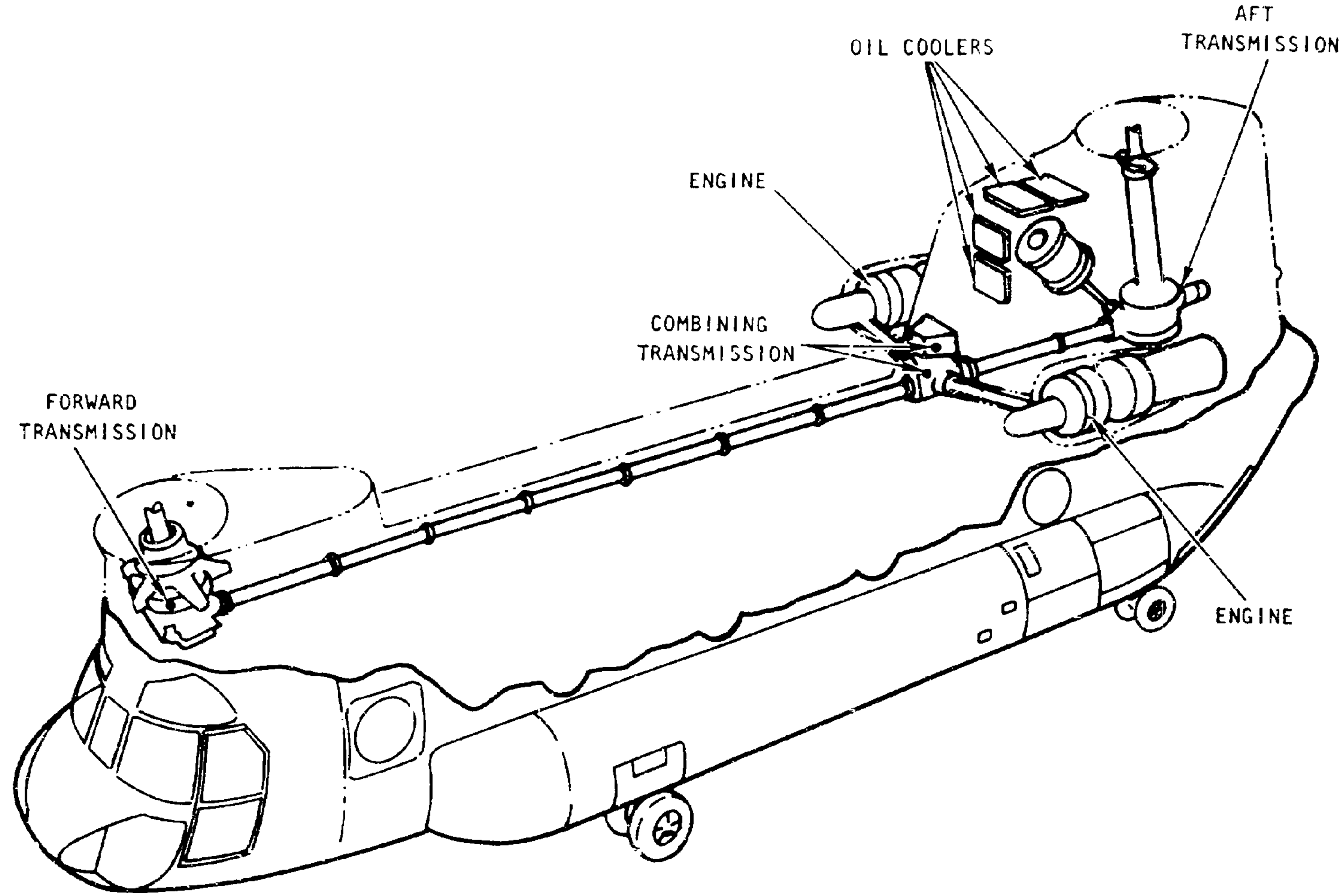


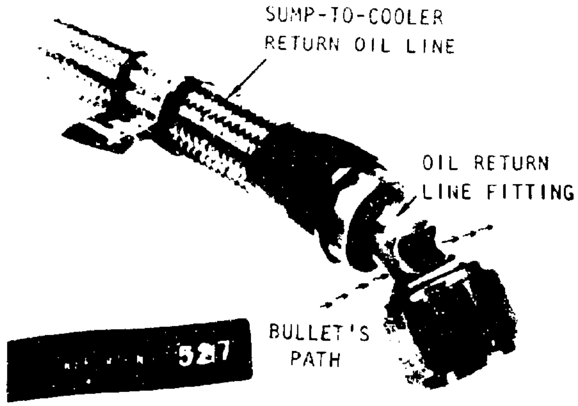
Figure 107. CH-47 Power Transmission System.

4.7.2.1 Loss of Lubrication: The lubrication system for most present day helicopter transmissions is not self-contained and usually consists of externally mounted components such as filters, coolers, and interconnecting lines or hoses. Most lubrication systems consist of a wet sump that recirculates oil to lubricate and cool the bearings and gears. The cooling requirements are usually much greater than lubrication requirements. The number and size of lubrication system components vary from one aircraft to another but, in general, they amount to a significantly large exposed area. Probability of an oil leak developing increases significantly with increasing lubrication system components and complexity. Even low velocity bullets and fragments find little difficulty in perforating the "soft" aircraft skin, structure and, most important, the exposed lubrication system components. Figure 108 shows a few typical examples of projectile damaged components which illustrates the "soft," easy to perforate, characteristics that result in oil leakage.

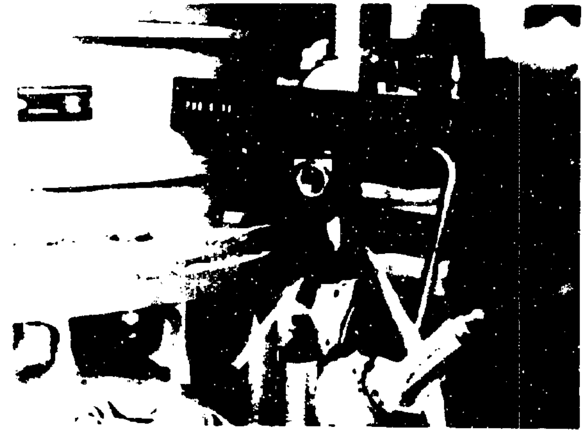
Loss of lubrication failures are most often related to the bearings, where loss of heat removal and thermal imbalance result in bearing seizure. Bearing failures, in some cases, cause misalignment of gear meshes, resulting in heavy scoring, extreme temperatures, and eventually gear teeth melting as shown in Figure 109. Failures are often catastrophic, causing transmission case rupture and fire after input pinion failures, and main rotor seizure after planetary assembly failures. In some applications, loss of lubrication causes loss of clearance and backlash in gear meshes which, in turn, leads to complete loss of the gear teeth.[93,94]

Projectile impacts on many areas of the transmission/gearbox housings and supports cause significant damage, especially against less ductile materials such as castings; however, loss of their function occurs only when large quantities of oil can leak out. Figures 110 and 111 illustrate typical projectile entrance and exit hole damage to a main transmission housing.

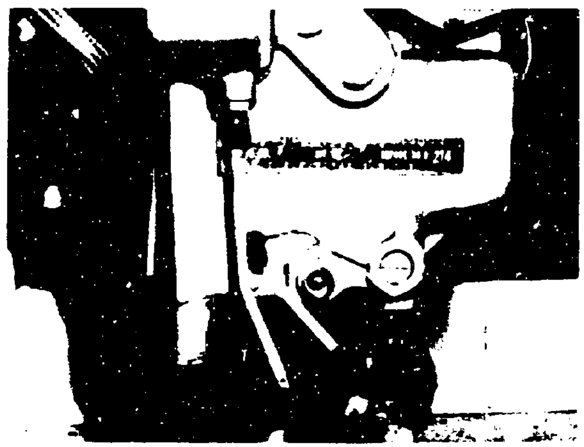
4.7.2.2 Direct Projectile Damage: Power train components, mainly bearings, gears, and shafts, are susceptible to primary projectile damage mechanisms, which usually results in either immediate loss of the units function, or extended operation is possible before failure occurs. Projectile impacts directly on high-speed bearings usually cause significant damage to them and, in some cases, are aggravated by the loss of oil. The gears, in general, tend to resist damage from projectile impacts much better than bearings; however, chips and debris from either the projectile or gear can jam the oil pump, causing loss of lubrication.



OIL LINE FITTING DAMAGE



OIL DELIVERY TUBE DAMAGE



TUMBLED BULLET DAMAGE TO SUMP (ENTRANCE)

TUMBLED BULLET DAMAGE TO SUMP (EXIT SIDE)

Figure 108. Damaged Oil Lubrication Components.

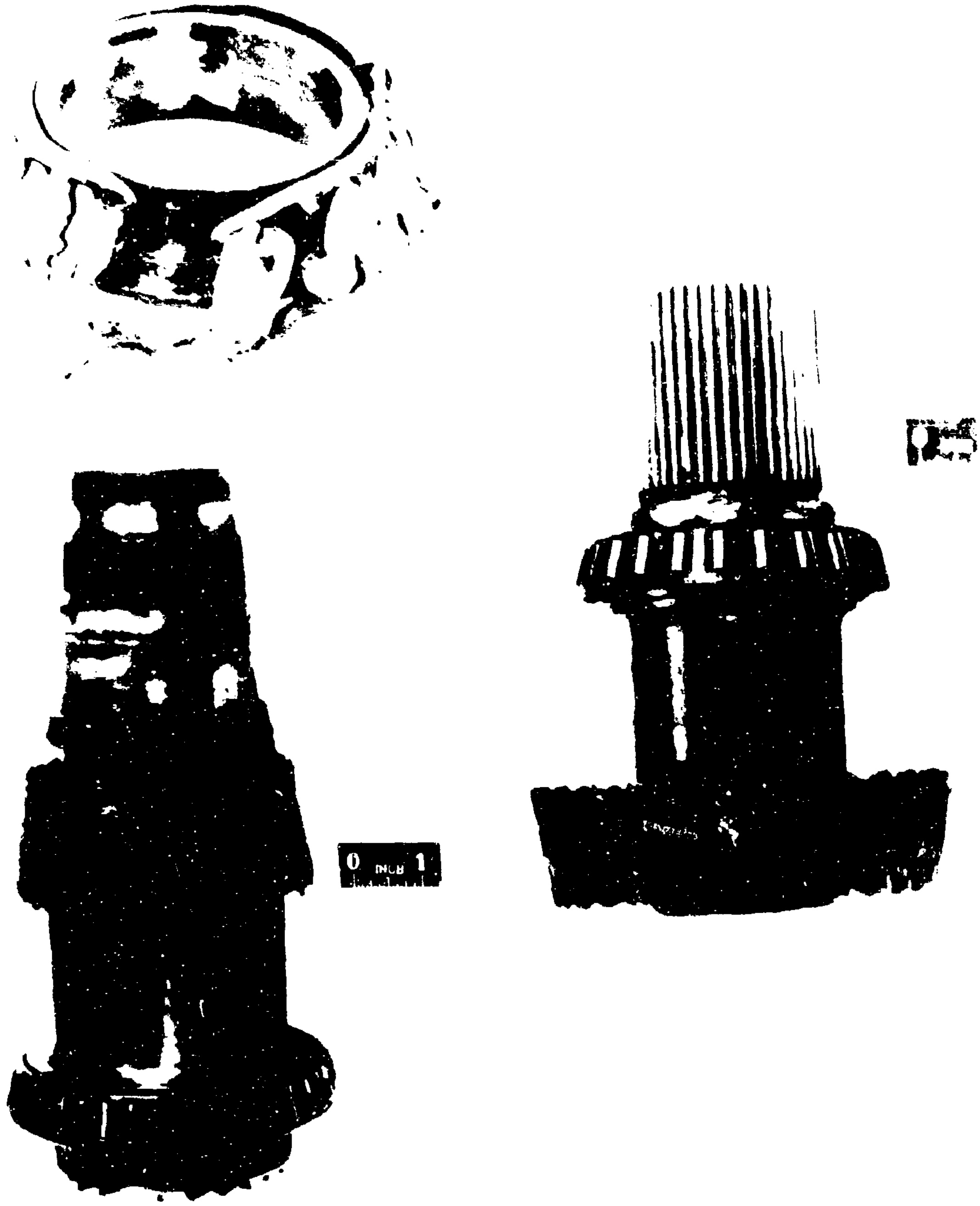


Figure 109. Gear Teeth Damage Due to Misalignment Caused by Bearing Failure.

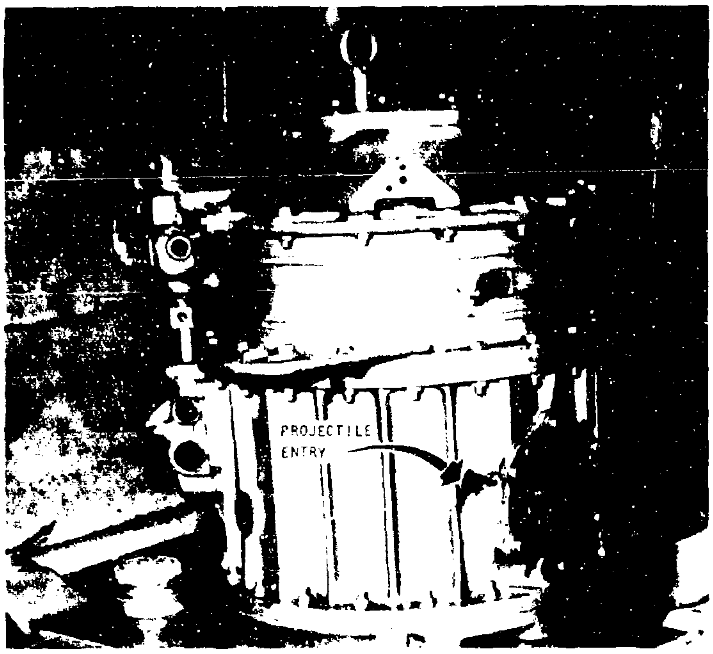


Figure 110. Main Transmission Housing Damage.

Figure 111. Main Transmission Housing Projectile Exit Damage.

Projectile impacts on drive shafts can cause immediate severence of the shaft, especially if the hit is near the bottom or top surface, or the projectile impacts in a tumbled or yawed condition. Figure 112 illustrates the critical impact areas for a typical drive shaft. This area varies with shaft material properties, diameter, and thickness, as well as projectile size and orientation at impact. Figure 113 shows the results of a typical projectile impact on a drive shaft in the critical impact area where operating loads caused complete failure.

4.7.3 DESIGN CONSIDERATIONS

The operational requirements for a rotary- or fixed-wing aircraft dictate the basic load requirements of power transmission or propeller gearboxes. These power requirements must be translated into design concepts that incorporate the most beneficial combination of survivability, reliability, safety, and maintenance features. For rotary-wing aircraft, power transmissions, shafting, and gearboxes are used. The following are survivability enhancement techniques that should be considered for initial and retrofit design efforts.

4.7.3.1 Transmission/Gearbox Lubrication: Initial Design: Damage tolerance techniques to minimize or prevent failure due to lubrication system damage can provide significant benefits for little or no penalties if incorporated into the initial design. Minimizing the probability of lubrication system failures has been researched and studied extensively during the past decade. Figure 114 illustrates many of the alternative solutions that have been considered for helicopter main transmission system. Reference 73 contains the results of feasibility and preliminary design study for various integral cooling systems. It indicates that two methods, rotor shaft and oil sump coolers, can provide relatively efficient means to minimize system vulnerability. These two methods are shown schematically in Figures 115 and 116 with the basic principles of operation illustrated for a specific application The rotor shaft cooler uses the main transmission rotor shaft as effective natural masking of the oil cooling system heat exchanger. In the oil sump cooler arrangement, exposed critical areas for the heat exchanger are reduced, with the cargo hoist acting as a natural masking against enemy gunfire. This concept would lend itself to helicopter configurations where the rotor shaft cooling concept would not be incorporated.

Annular-type helicopter transmission oil cooler systems have been investigated and found to be feasible. This concept differs from conventional normal crossflow, plate-fin heat exchangers used in existing helicopters.[78]

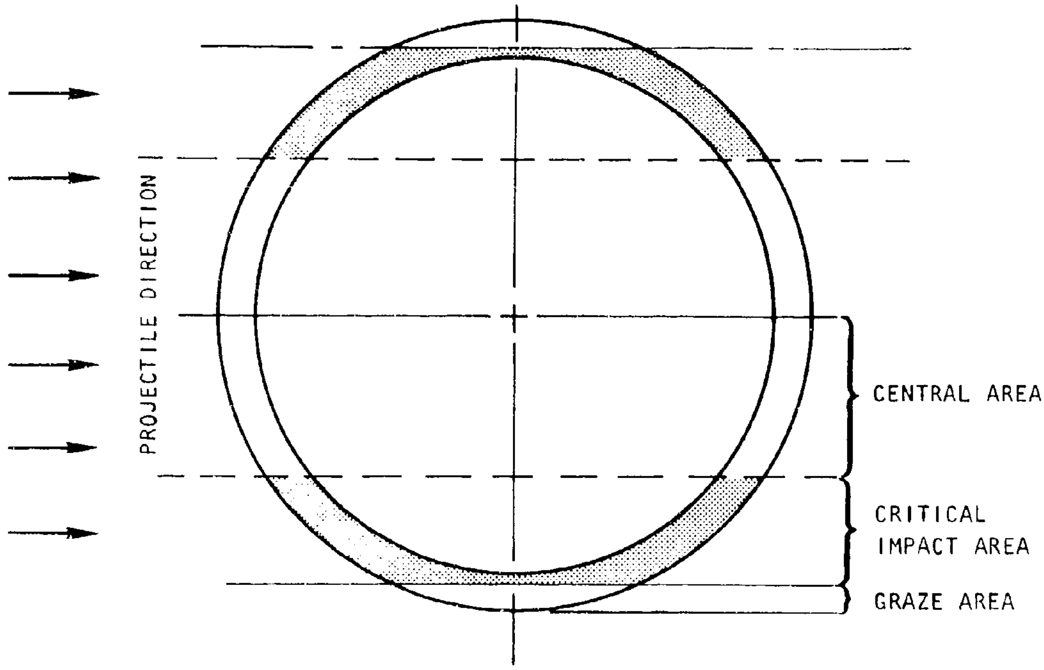


Figure 112. Critical Impact Area of Drive Shafts.

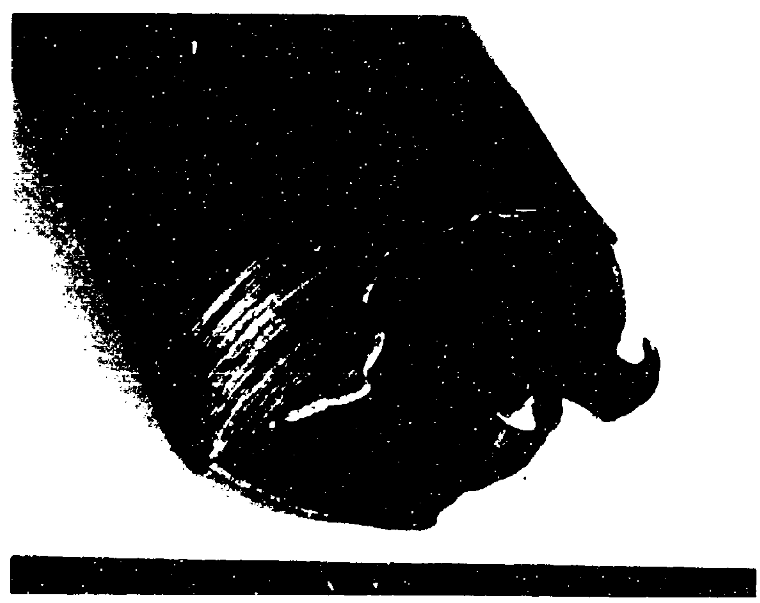


Figure 113. Drive Shaft Ballistic Damage and Failure.

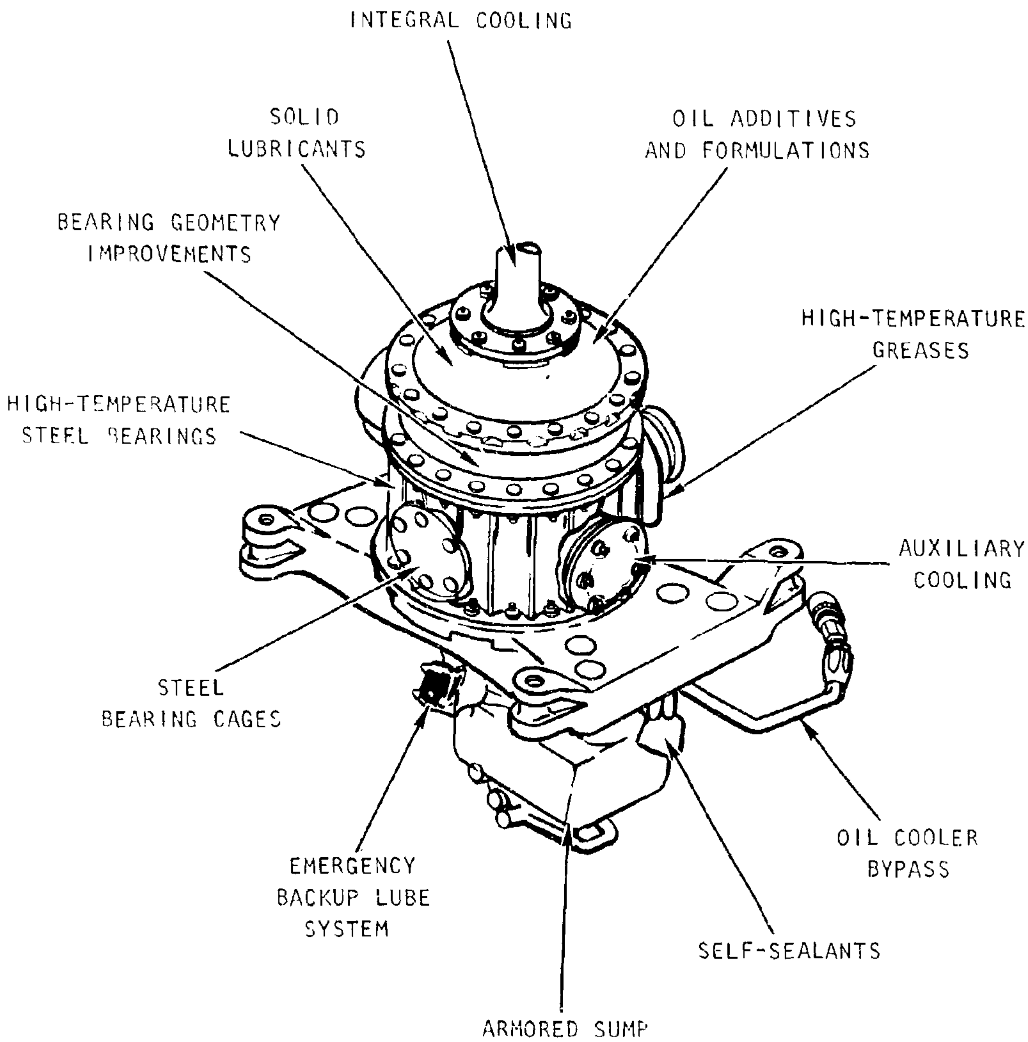


Figure 114. Alternate Solutions to Reduce Vulnerability of Main Transmissions.

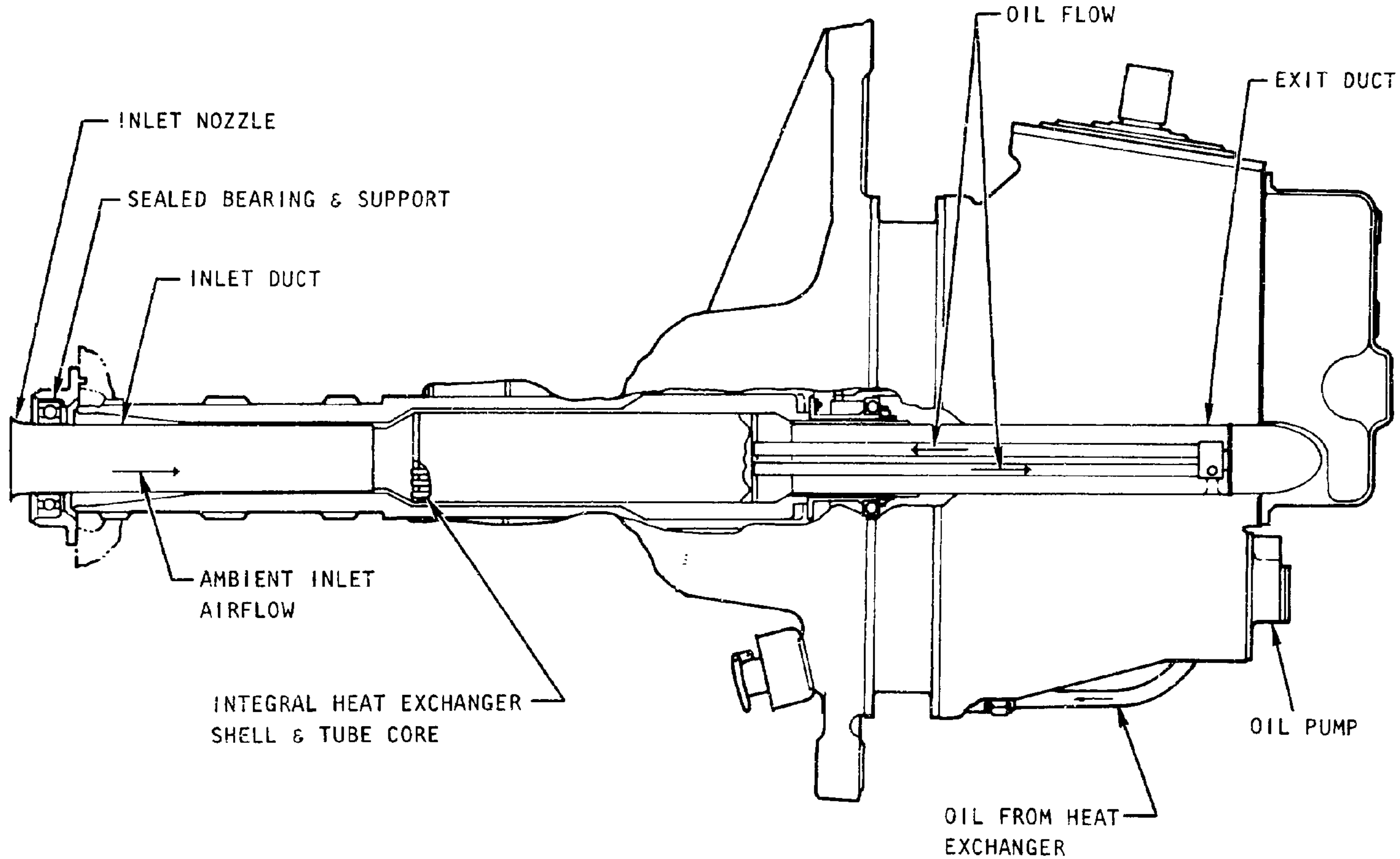


Figure 115. Rotor Shaft Oil Cooling System Concept.

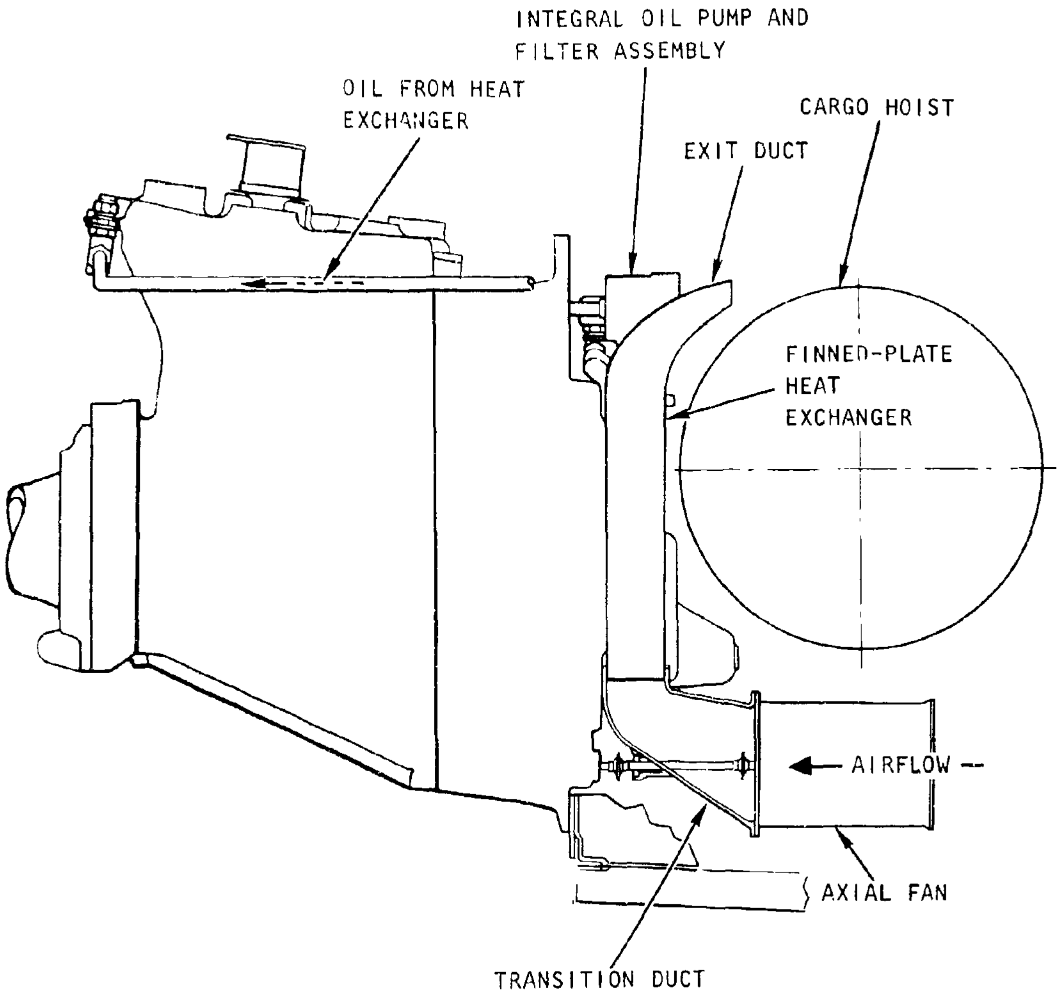


Figure 116. Oil Sump Cooling System Concept.

The annular oil cooler uses a radially directed airflow coupled with a circumferential oil flow, which does not result in a true 90-degree cross-flow heat exchanger. Figure 117 illustrates its basic design features. Heated oil is introduced into a divided manifold, which directs it in a counterclockwise direction through stacked core sections. Cooling air is directed radially inward or outward to achieve forced convection heat transfer. The cooled oil is then returned to the transmission system through the outlet port.

Research has also been directed towards the use of solid lubricants in transmissions to extend their useful operational life if the lubricating fluid is lost. Results of research efforts have shown that bearings with solid-lubricant retainers, and gears using solid lubricant idlers will perform satisfactorily during normal operation with oil lubrication, and will provide significant operational life after lubrication oil loss in certain helicopter transmission applications. Teflon solid-lubricant-filled silver alloy matrix was found to provide the best long-term operation at a speed of 1,000 rpm. Reliable long-term operation at 2,000 rpm was achieved by use of tungsten diselenide/gallium-indium composites. Auxiliary gas or airflow cooling of helicopter gearbox pinion gear bearings within a transmission, following loss of lubricating oil, was found to extend the useful operational time from 1 minute to 10 - 15 minutes.[74]

4.7.3.2 Transmission/Gearbox Lubrication - Retrofit: Minimizing the amount and rate of helicopter transmission lubrication fluid loss should receive design consideration for retrofit, and also in the initial design for special severe environments. A number of self-sealing materials can be used to perform this function, with Vithane being one of the more promising materials. It can be applied directly to the outer surfaces of reservoirs and large lines. Its effectiveness is dependent upon the size, type, and impact conditions of the enemy projectiles. Specific design guidance is provided in the detail design considerations in this section.

Bypass lubrication should be considered for applications where oil coolers external to the transmission are in use or cannot be avoided in a new design concept. This technique isolates the transmission oil sump from the oil cooler circuit when a leak is detected or the oil level declines to a predetermined level. Figure 118 illustrates the basic system technique. The bypass valve is actuated by an automatic system or by the crew when a leak is detected. This diverts the pump output flow through a bypass circuit line directly back to oil sump area in the transmission mix box.

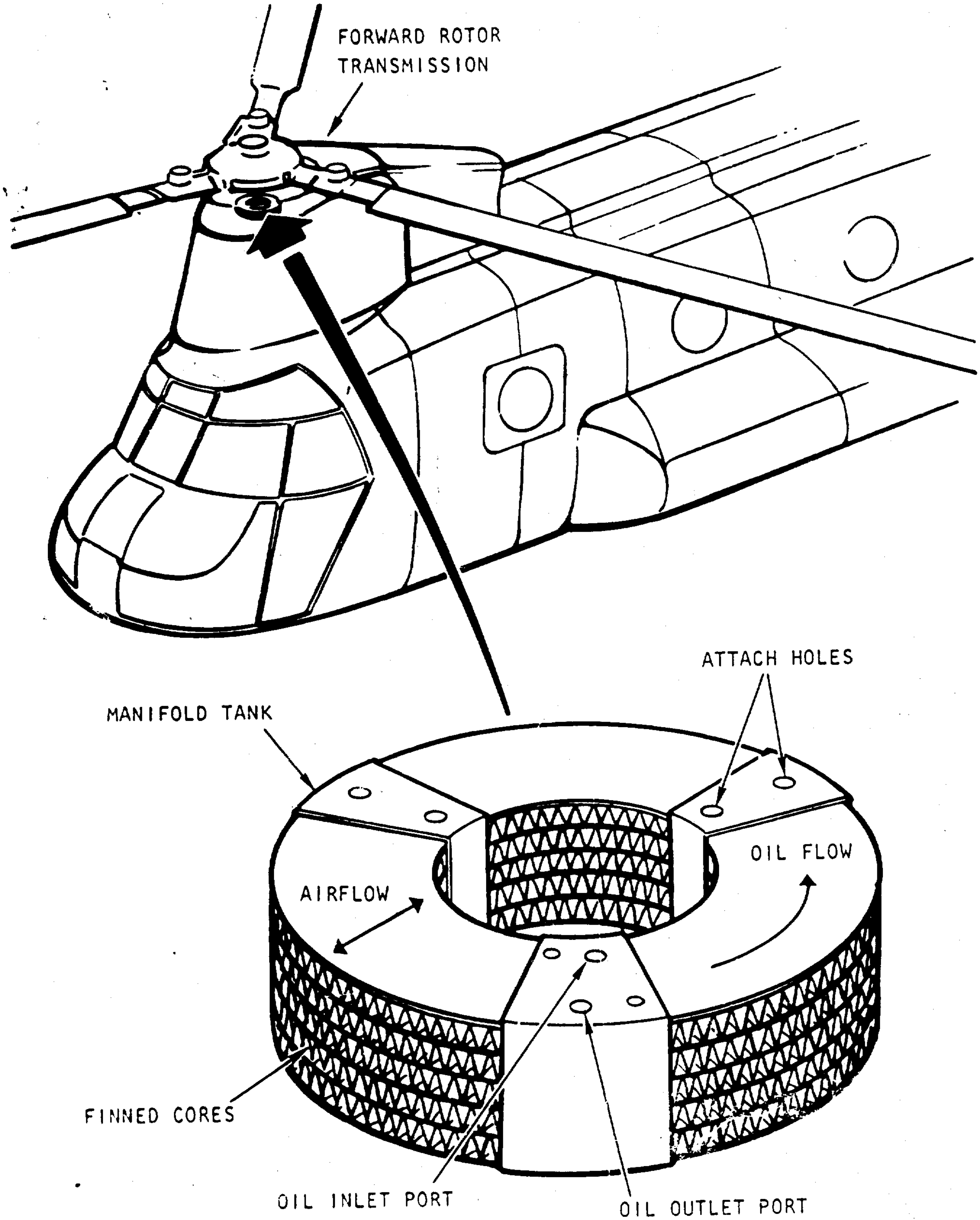


Figure 117. Annular Oil Cooler Concept.

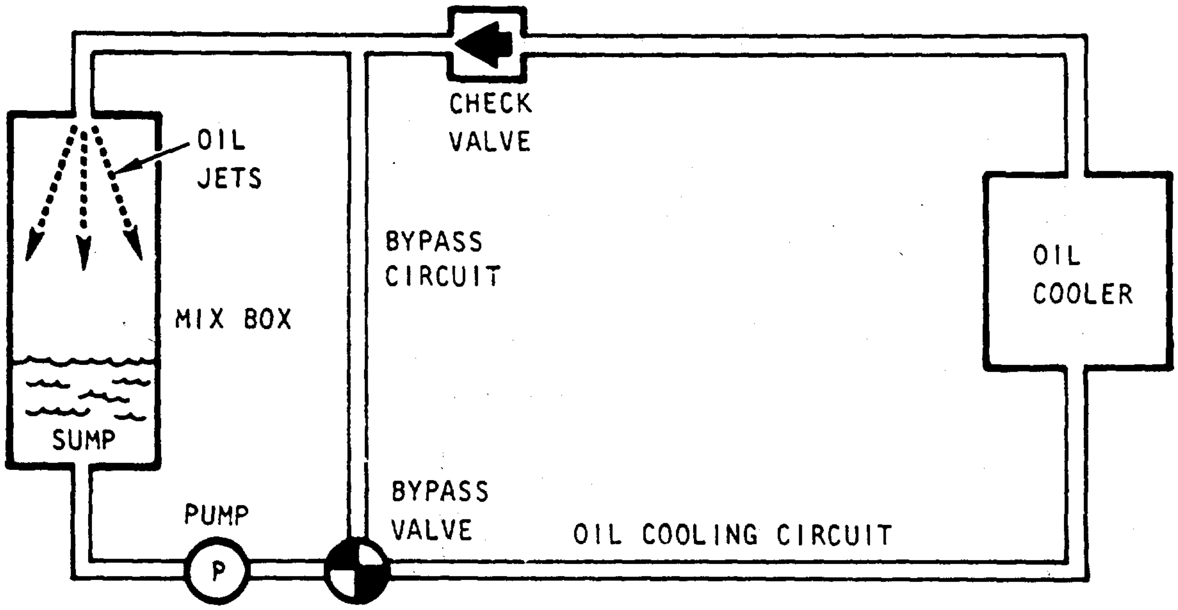


Figure 118. Mix Box - Bypass Lubricating System.

A check valve is used to prevent flow of oil back into the oil cooler and associated lines where the ballistic damage has most probably occurred. Without the heat rejection capability of the oil cooler, the temperature of the unit's bearings will rise. Tests indicate that the temperature rise will be gradual and will stabilize long enough to enable the aircraft to return to its home base or to an area where a safe forced landing could be made. Figure 119 shows the temperature rise time history for the combining mix box of the CH-46A. The temperature rise from normal to over 400° F for the nine major bearings took approximately 30 minutes. The temperature stabilized at this point for a total of 70 minutes, at which time the test was terminated. Analysis of the test results indicated that bearing velocities are the dominating factor in temperature rise rates.[76]

Backup or auxilliary lubrication systems should also be considered. This approach, shown schematically in Figure 120, incorporates a small backup sump and pump to provide minimal oil flow to critical areas of the transmission. Ideally, all auxilliary oil lines should be located within the gearbox, and the sump and pump should be protected.

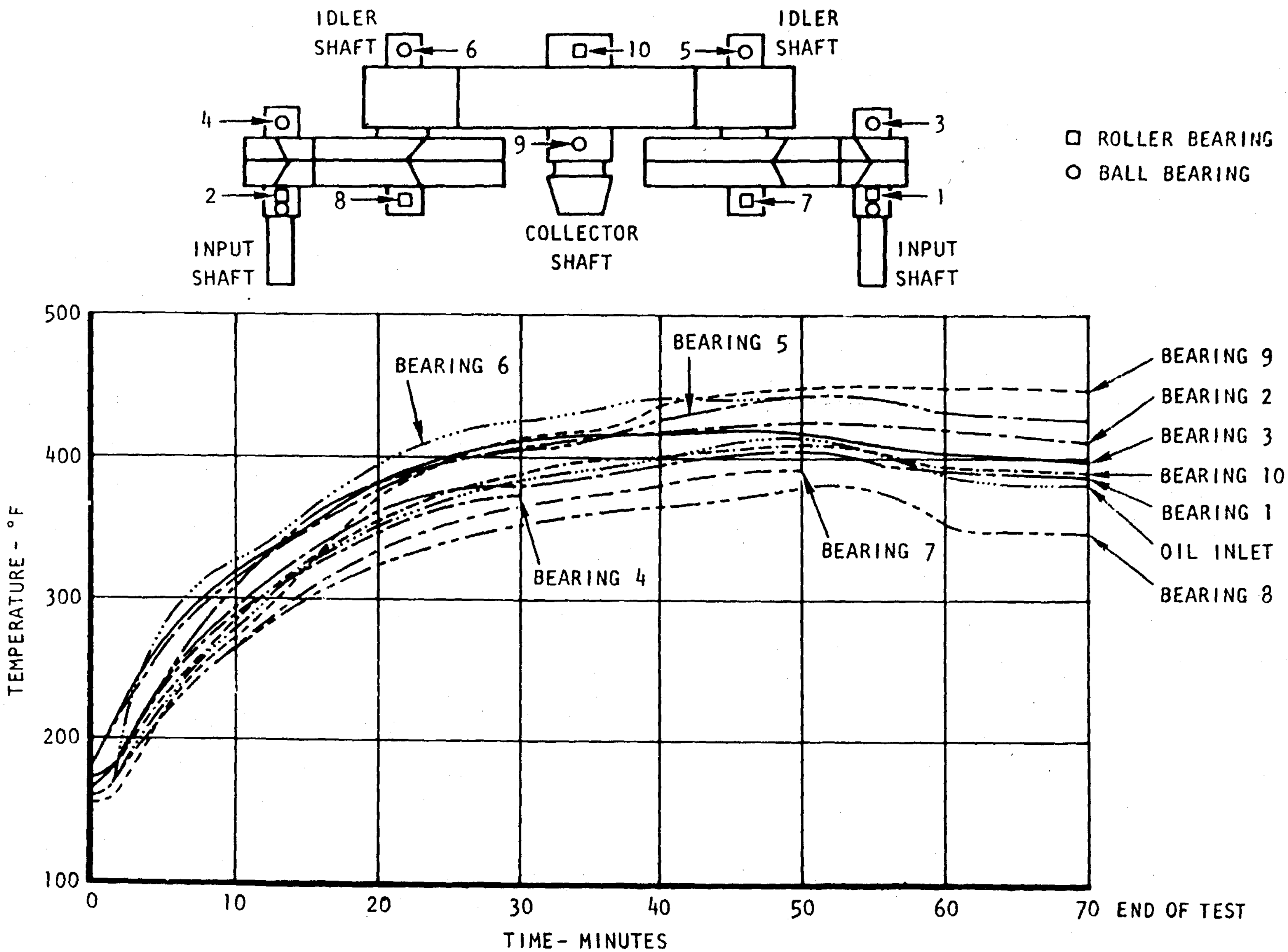


Figure 119. Mix Box - Bypass Lubrication Test Temperature History.

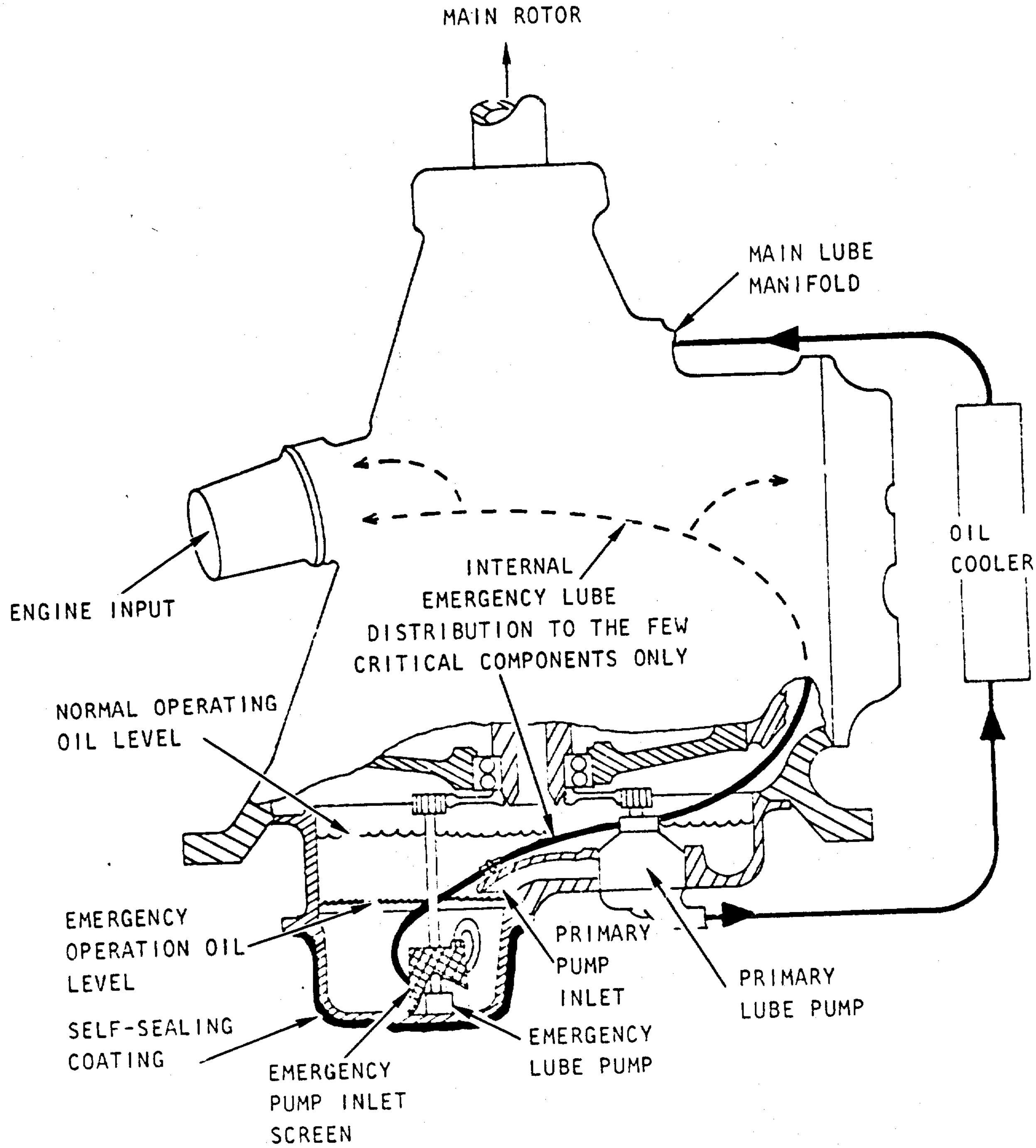


Figure 120. Backup or Emergency Lubrication System for Helicopter Transmissions.

4.7.3.3 Transmission/Gearbox Housings: Material selection is a primary consideration for transmission and gearbox housings. The selection process should evaluate both ballistic-tolerant and ballistic-resistant material candidates. For those portions of the housing where a degree of penetration can be tolerated or is effectively masked or otherwise protected, material with high fracture toughness and ductility should be used. Where penetration of a transmission or gearbox housing by a projectile cannot be tolerated, ballistic protection should be considered. Parasitic armor can be used for protection of existing equipment as illustrated in Figures 121 and 122. The first figure shows a transmission shield fabricated from dual hardness steel armor designed to defeat a .30-caliber armor-piercing (AP) projectile for a CH-47 engine transmission. As can be seen, the armor is directionally oriented to the aspect angles of hostile gunfire. Figure 122 shows a shield fabricated from dual hardness steel armor for a CH-47 main rotor transmission forward oil sump. The oil sump itself could also be fabricated directly from dual-hardness steel armor.

Special consideration should be given to major or critical high-load, high-speed bearing supports. Catastrophic failure of a transmission or gearbox can occur if the main load-bearing support fails or the bearing itself is fractured from the impact of a projectile. Bearing support structure should be designed for ruggedness and toughness with redundant load paths. Where protection of large-size major bearings is essential, consider the use of ballistic-resistant bearing sleeves that will provide the degree of protection required. Figure 123 shows a bearing sleeve, for the CH-47 high-speed transmission, that has been fabricated from DPSA material.

4.7.3.4 Drive Shaft Design: Helicopter drive-shafting is required to transmit power under conditions of angular, axial, and lateral misalignment of the driving and driven equipment. As improvments in gas turbine engine power and speed are made, corresponding increases in shafting rotational speeds will be required. The typical speed range for drive shafts to the transmission has been between 6,000 and 8,000 rpm and 4,000 rpm for tail rotor systems. Shafting is being developed to operate in the 15,000- to 30,000-rpm range for drive shafts, and 4,000- to 6,000-rpm for tail rotor systems. Design of such high-speed shafting systems dictates careful consideration of design techniques and features to prevent or minimize failures due to small-arms projectile damage. Particular attention must be paid to systems that are designed to operate at or near critical speeds that occur when the centrifugal force due to initial unbalance exceeds the internal elastic restoring force, or shaft stiffness, and the "whirl" deflection theoretically increases to infinity. The "whirl," caused by ballistic damage, may cause bending stresses in the shaft which would exceed the strength capability. Shaft design, therefore, must provide for

Figure 121. CH-47 Experimental High-Speed Transmission Shield.

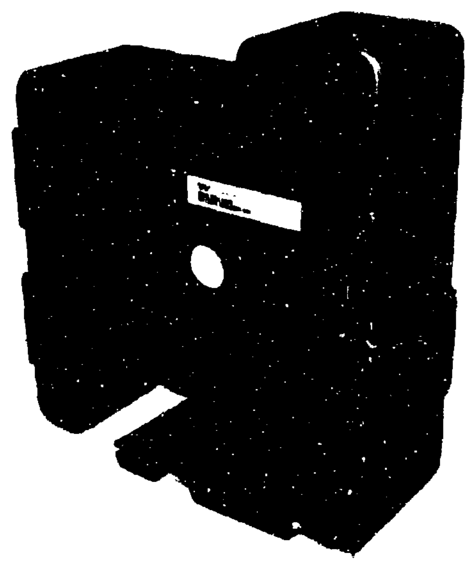


Figure 122. CH-47 Experimental Main Rotor Transmission Forward Sump Shield.

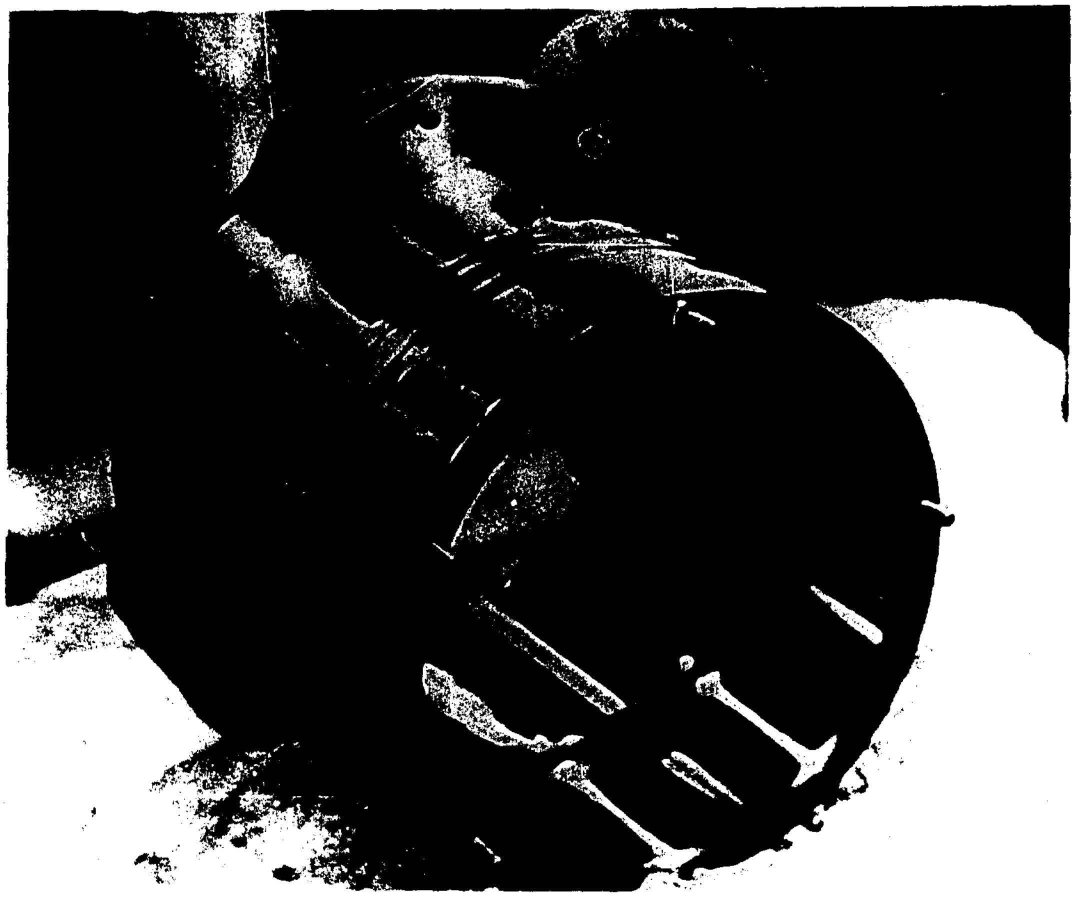


Figure 123. Experimental DPSA Bearing Sleeve.

safe operation after being hit by single or multiple projectiles. Shaft diameters and wall thickness ratios must be evaluated to determine the amount of material that will be lost and the remaining strength for the size and type of projectiles that may be encountered. Large, thin-wall shafts are less susceptible to failure from ballistic damage than small, thick-wall shafts. Shaft couplings and intermediate shaft supports or hangers must also be designed for ballistic damage tolerance to minimize failure or malfunction from ballistic impacts. Materials with high fracture toughness must be considered for maximum protection.

4.7.3.5 Gearing Design: Transmission and gearbox design requirements determine the loads that must be transmitted by the individual gears in each unit. Destruction or jamming of any one of these can destroy or degrade its capability to perform its function. Where protection of the unit's internal gears is marginal or cannot be provided, consideration

should be given to incorporating ballistic-damage-tolerance features in the gear trains. Wide section gears should be used in preference to narrow-width section types. This will permit a portion of the gear to be broken out or removed by a projectile impact and still retain a degree of operation. Figure 124 shows a wide section ring gear that sustained a projectile hit and was able to continue to operate. Tough, rather than brittle, gear material should be used to minimize the effects of ballistic impacts.

4.7.3.6 Bearing Selection: Bearings with inherent capability to operate after loss of normal lubrication or cooling should be considered and selected for major critical bearing applications in transmissions and/or gearboxes. The state of the art in this field is changing rapidly, and the designer should consult with bearing manufacturers to obtain the latest information and candidate bearings available. Careful consideration should be given to the number of and size of bearings selected. A larger bearing may be more advantageous than several smaller bearings, depending upon rotational speeds and heat transfer or distribution characteristics of the specific installation. The amount of heat generation and bearing high-temperature operating capabilities must be also considered in the material selection of the bearing.

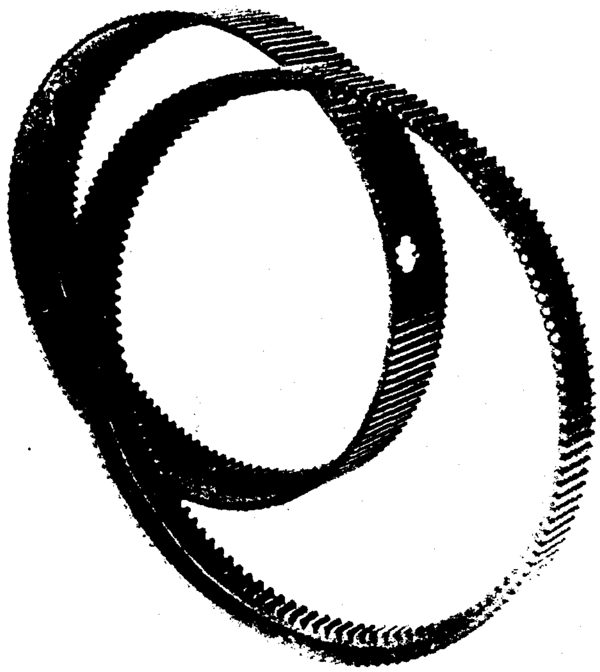


Figure 124. Damaged Ring Gear.

4.8 ENVIRONMENTAL CONTROL SYSTEMS

4.8.1 INTRODUCTION

Environmental control systems are comprised of pressurizing, cooling, heating, ventilating, moisture control, oxygen, and environmental protection subsystems and components. Portions of these subsystems can be essential for mission completion and/or aircrew survival.

4.8.2 DAMAGE EFFECTS

The environmental control system (ECS) includes the pressurizing, cooling/heating, ventilating, contamination control, and moisture control subsystems. The general specification for these systems is MIL-E-38453. The ECS is rarely listed as the cause of a mission abort because of the complexity of the interface between the ECS and all other subsystems in the aircraft. The secondary effects following an ECS failure are normally entered on the accident and damage reports under the heading of primary cause. Table XXIV is an abbreviated listing of aborted missions that are representative of this situation. The designer can see how easily the original cause can be overshadowed by the secondary effect. It is also easily recognized that small-arms fire is capable of causing the failures that are listed. This listing was compiled for a wide range of low- and high-performance aircraft to provide the designer with a comprehensive understanding of secondary hazard considerations. It indicates the importance of evaluating the effect of the aircraft's operational environment along with the primary failure that may be caused by gunfire. The altitude, speed, maneuvers, weather, mission objectives, and terrain can be contributing factors to a condition that could cause loss of mission or loss of the aircraft. Such hazards must be considered by the designer early in the design process to prevent or minimize them in his individual design configurati

The designer should, therefore, identify the portion of the ECS that is essential for mission completion and for aircrew survival. The ECS should be designed to service the mission-essential elements of the other aircraft subsystems in a suitable order of priority to enhance total system survivability and capability if subjected to small-arms fire.

4.8.3 DESIGN CRITERIA

4.8.3.1 Cooling/Heating: Environmental cooling and heating systems are used to maintain the temperature of crew stations or subsystems within the limits required for comfort and proper operating conditions. Design systems to service mission-critical aircrew stations and equipment in order of priority for mission completion and aircrew/aircraft survival.[32]

TABLE XXIV. REPRESENTATIVE MISSION ABORTS DUE TO ECS PROBLEMS

Reason for Mission Abort	Component/Assembly Failed or Damaged	Secondary Problems
Loss of Aircraft	Bleed-air duct	Loss of flight control
	Air-conditioning system	Fogging of windshield
	Rain removal air duct	Fire
Loss of Cabin Pressure	Anti-icing duct	Electronics overheat
	Hot-air duct	
	Air-conditioner duct	
	Duct coupler	
Engine(s) Shutdown	Rain removal attachment	Smoke in cockpit
	Cracked heat exchanger	Oil pressure to zero
	Windshield blower valve	Generator off-the-line
	Air pump valve	Hot cockpit
	Hot-air duct	Smoke and fog in cockpit
	7th-stage air line	
	Bleed-air duct	
	Nose refrigeration duct	
	Generator cooling duct	
	Anti-icing duct	Engine fire
	Fire can and duct	

TABLE XXIV - Continued

Reason for Mission Abort	Component/Assembly Failed or Damaged	Secondary Problems
Human Incapacitation	Mixer valve	Frostbite - copilot
	Cockpit heater	Smoke and burns - pilot
	Canopy seal	Hypoxia - crew
	Primary heat exchanger	Nausea - pilot
	Window heater terminal	Nauseous fumes - cockpit
	Isobaric control	Bends - navigator
	Shutoff valve	Hypoxia - navigator
	Door seal	Bends - crew
	Water separator	
	Pressure controller	Hypoxia - crew
	Temperature control	Electrical fumes - eye
	Magnetic amplifier	irritation - aircrew
	Temperature control box	Dehydration - pilot
	Air modulating valve	Burns - pilot
	Safety valve seal	Hypoxia - pilot
	Pressure regulator	Bends - gunner
		Bends - pilot and EWO
	Catalytic filter	Bronchial, throat, and chest irritation

TABLE XXIV - Continued

Reason for Mission Abort	Component/Assembly Failed or Damaged	Secondary Problems
Miscellaneous	Auxiliary cooling tap-off line	Radar and Doppler failure
	Bleed-air manifold	Hydraulic failure, flight control failure, smoke in cockpit
	Camera heat duct	Short-circuited wires in servo's (elevator, rudder) yaw damper
	Ram-air duct	Interference with elevator control cable caused aircraft to porpoise on low-level run

Consider the following techniques to obtain acceptable survival values when aircraft is subjected to ballistic weapon effects:

- Provide redundant or emergency cooling and heating systems that will provide necessary temperature control for time necessary for mission completion or crew/aircraft recovery.

- Provide emergency, automatic, or aircrew-operated, shutoff or isolation of high-temperature heating systems, the failure or malfunction of which, caused by weapon effects, would result in unacceptable crew comfort or performance, other subsystem malfunction or failure, or secondary hazard conditions, such as internal fires, smoke, and toxic fumes.

- Locate refrigeration unit components (heat exchangers, air cycle machine, etc.) so as to provide natural or armor shielding from weapon effects.

- Construct components to resist shattering or explosive disintegration that could cause damage or failure of other subsystems, or injury to personnel from fragmentation.

- Keep high-temperature gas/air line pressures as low as possible to minimize secondary hazards from penetration of such lines by projectiles or fragments.

- Route high-pressure and high-temperature gas/air lines to avoid potential fire hazard areas. Route such lines in channels or other heavy structure to isolate them from other subsystems. See Figure 125.

- Position hot gas/air line connections in areas where their failure from weapon effects will cause the least secondary hazard from release of high-temperature air/gas.

- Design high-speed rotating equipment of refrigeration unit so that its containment capability following exposure to weapon effects is not lost.

4.8.3.2 Ventilation/Contamination: Proper ventilation and contamination control may be essential for specific subsystem performance needed to achieve mission completion and/or aircrew/aircraft survival. These subsystems may include aircrew stations, engine bays, armament functions, and other critical compartments. Provide priorities for subsystem operation, and incorporate these into the basic design phase to direct ventilation

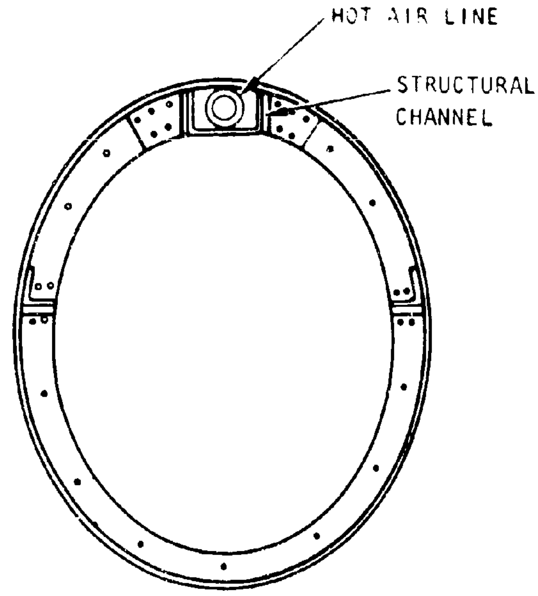


Figure 125. Hot Air Line Isolation.

to those subsystems whose failure or malfunction would degrade the aircraft/aircrew survivability or mission completion. Consider the following techniques to obtain optimum survival of the aircraft/aircrew:

- Provide positive ventilation to those compartments and areas where flammable vapors or liquids may migrate if their containers have been damaged by ballistic weapon effects.
- Design and/or construct system components to resist cracking and shattering when struck by a projectile.
- Route ventilation lines to avoid secondary hazard areas where fire explosions, smoke, or toxic fumes may be ingested into aircrew stations.
- Use ram-air emergency ventilation for aircrew stations and critical subsystems when the normal system has failed or malfunctioned.

4.8.3.3 Moisture Control: Moisture control is required for the aircrew compartment and electronic equipment. Introduction of moisture into the aircrew compartment because of control failure from weapon effects could result in poor visibility for the aircrew, and the moisture could cause failure or malfunction of essential electronic equipment. In applications

where moisture control for electronic equipment is accomplished through the use of a liquid coolant fluid, secondary hazards may be caused by the release of coolant liquid or vapor into the aircrew compartment area that would be detrimental to the crew's performance or health and lead to loss of the aircraft or to mission failure. In addition, a leak in the liquid coolant circuit due to combat damage will result in loss of cooling for the electronic equipment and subsequent failure of the electronic equipment. Consider the following techniques to enhance aircrew survival:

- Use an air coolant system in preference to a liquid coolant system where vulnerability of the latter is greater or would create an unacceptable secondary hazard.

- If a liquid coolant is used, select one that will prevent or minimize toxic or fire hazards.

- Avoid locating liquid coolant lines in aircrew station.

- Locate moisture controls where they will be provided natural masking from weapon effects.

4.8.3.4 ECS Installations: Insure that air flows from cockpit to cabin or afterstation. This is to prevent the movement of fire, smoke, or toxic gases from other parts of the aircraft into the cockpit area.

Materials used in the ECS should not emit toxic or explosive gases when exposed to elevated temperatures that are caused by weapon effects.

Materials used in the ECS should resist explosive shattering if struck by projectiles, fragments, or spallation.

Fire hazard due to high-temperature air may be minimized by isolation, precooling, and the use of noncombustible material in areas of potential hot-air impingement. Line routing shall prevent or minimize the hazards associated with weapon effects.

Mission-essential components shall be located in areas where they receive natural shielding or armor protection from weapon effects.

4.9 FLIGHT CONTROL SYSTEMS

4.9.1 INTRODUCTION

Stability and control of an aircraft is an essential factor in its ability to maintain a safe flight path. Combat experience has shown that flight

control systems of military aircraft are particularly vulnerable to small-arms fire. Extensive research and development effort has been expended on means to design more survivable flight control systems and components.[79-83]

There are two categories of flight control systems: primary and secondary. Primary controls are defined by MIL-F-9490 as those systems used to control the flight of the aircraft by means of the primary control surfaces, reaction controls, engine orientation, thrust deflection controls, etc. Secondary flight controls include all other systems that are used to supplement the primary flight control systems. These are trim, flap, dive recovery devices, etc. Such a system cannot be classified as secondary without analytical demonstration that lack of performance or malfunction will not affect safety of flight.

Considerable advancement in protection of control systems against ballistic damage has been made in recent years. The basic principles of current techniques are presented in this section to give the designer the greatest possible selection of options that can be applied to his specific configuration. One of the most sensitive factors in rotary-wing aircraft is the weight penalties that may be imposed for improved survivability for both initial design and operational aircraft retrofits. For existing designs, such weight increases degrade the performance and capability of the system. For new designs, increased system weight and costs are experienced. These factors must receive primary consideration in the selection of flight control survivability features. Figure 126 illustrates the relationship of relative weight to vulnerability for existing helicopter flight control systems, fly-by-wire concepts, ballistic tolerance concepts, and duplication/redundancy concepts with and without armor protection. Such factors for new designs must be considered early in the design concept process in order to avoid unnecessary penalties and/or redesign efforts. Continuing advancements are being made in this discipline to develop even more effective survivability techniques.

4.9.2 BALLISTIC DAMAGE EFFECTS

Impact of small-arms projectiles can create a number of damage mechanisms that can destroy or degrade the capability of flight control systems to perform their required functions. The primary weapon effects are projectile piercing, impact shock, and incendiary effects. Secondary damage mechanisms are spallation, creation of fires or explosions, distortion of structure and components, and liberation of damaging agents such as hot bleed air or corrosive materials. Each may have the ability to degrade the ability of a flight control system to operate by severing, shattering,

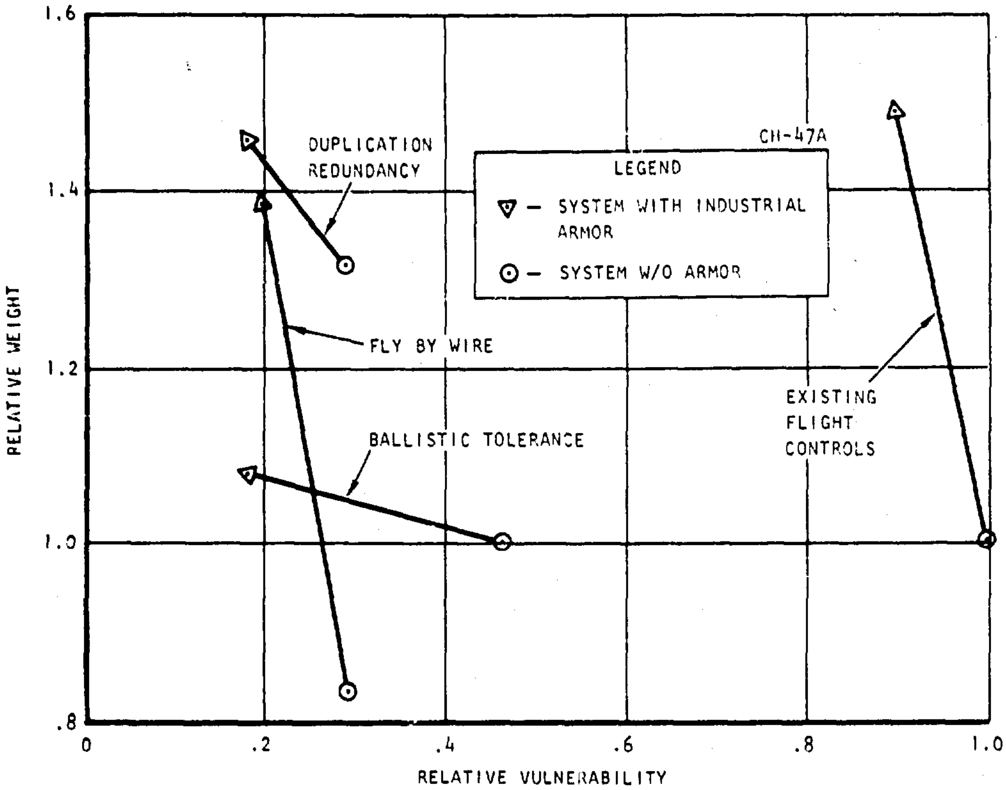


Figure 126. Relative Weight Versus Relative Vulnerability

or jamming mechanical linkages or components, as shown in Figures 127 through 129, and causing failure of electrical or hydraulic power systems required for system operation. High thermal conditions may cause material loss of strength, leading to failure or malfunction of the system element. Each portion of a flight control system must be examined to determine its failure modes in the range of weapon effects to which it may be exposed, and the effects of its damage upon system operation must be evaluated. By considering such damage effects, a systematic evaluation of means to prevent or minimize system vulnerability can be made to find the most effective combination of techniques that can be used. Battle damage failure mode and effect analyses can be used to systematically identify vulnerable components and sensitive areas within a control system design. A representative control system is shown in Figure 130. As can be seen, system redundancy is provided by two servo cylinders, each powered by separate hydraulic systems. This is a conditional redundancy, however, in that the failure mode of either system must exclude jamming that cannot be overcome by the undamaged unit. For jamming failure modes, the resultant effect on the overall system is locking of the system in the position it

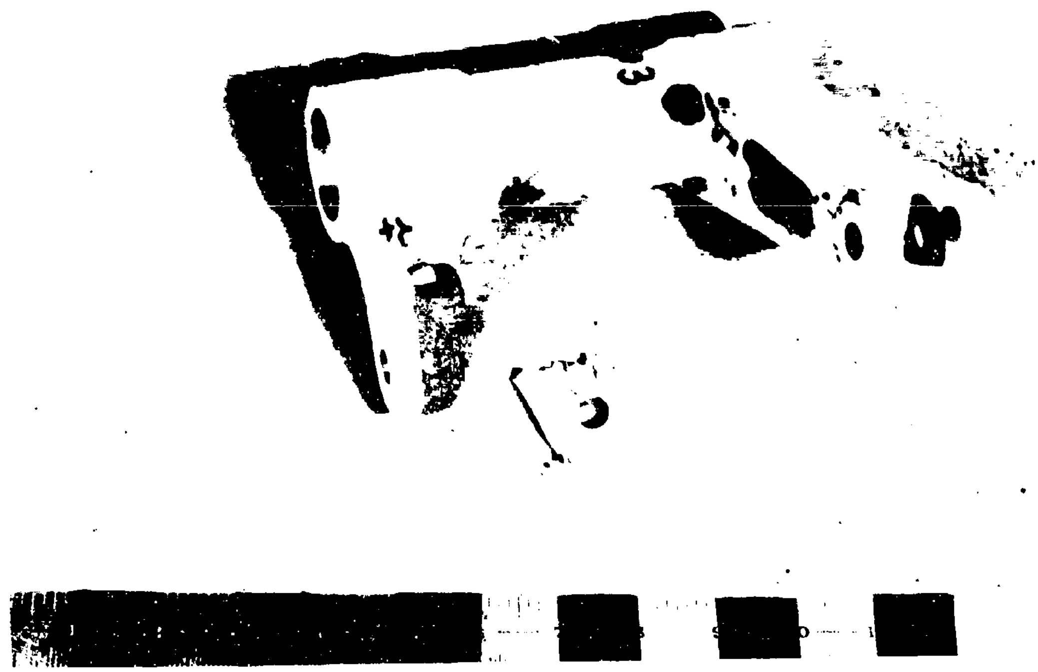


Figure 127. Damaged Bellcrank.

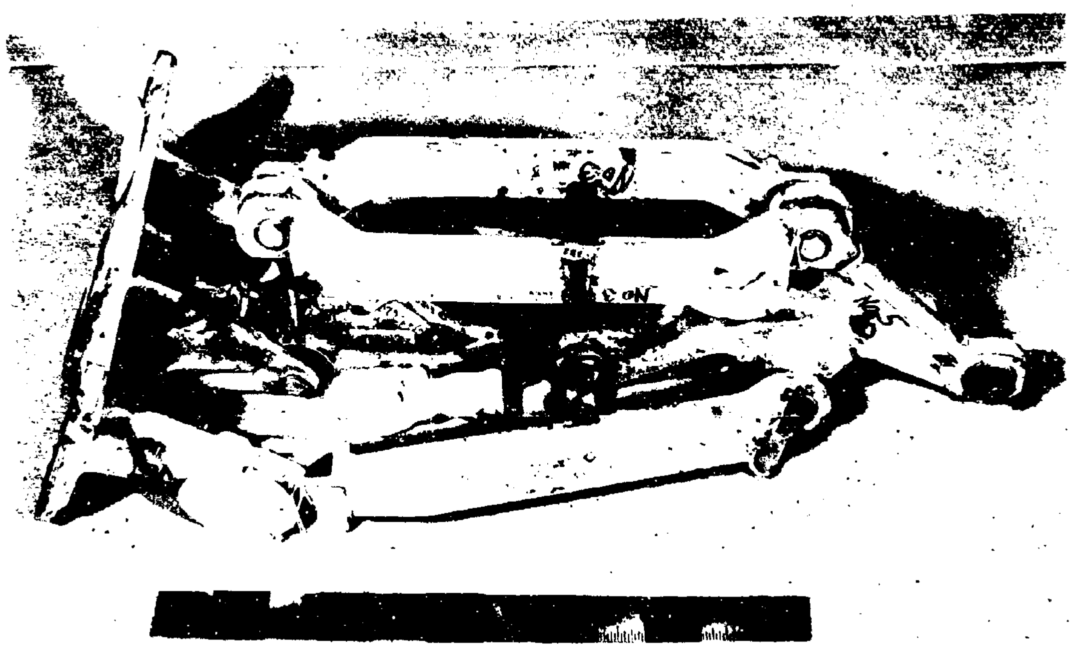


Figure 128. Flight Control Linkage.

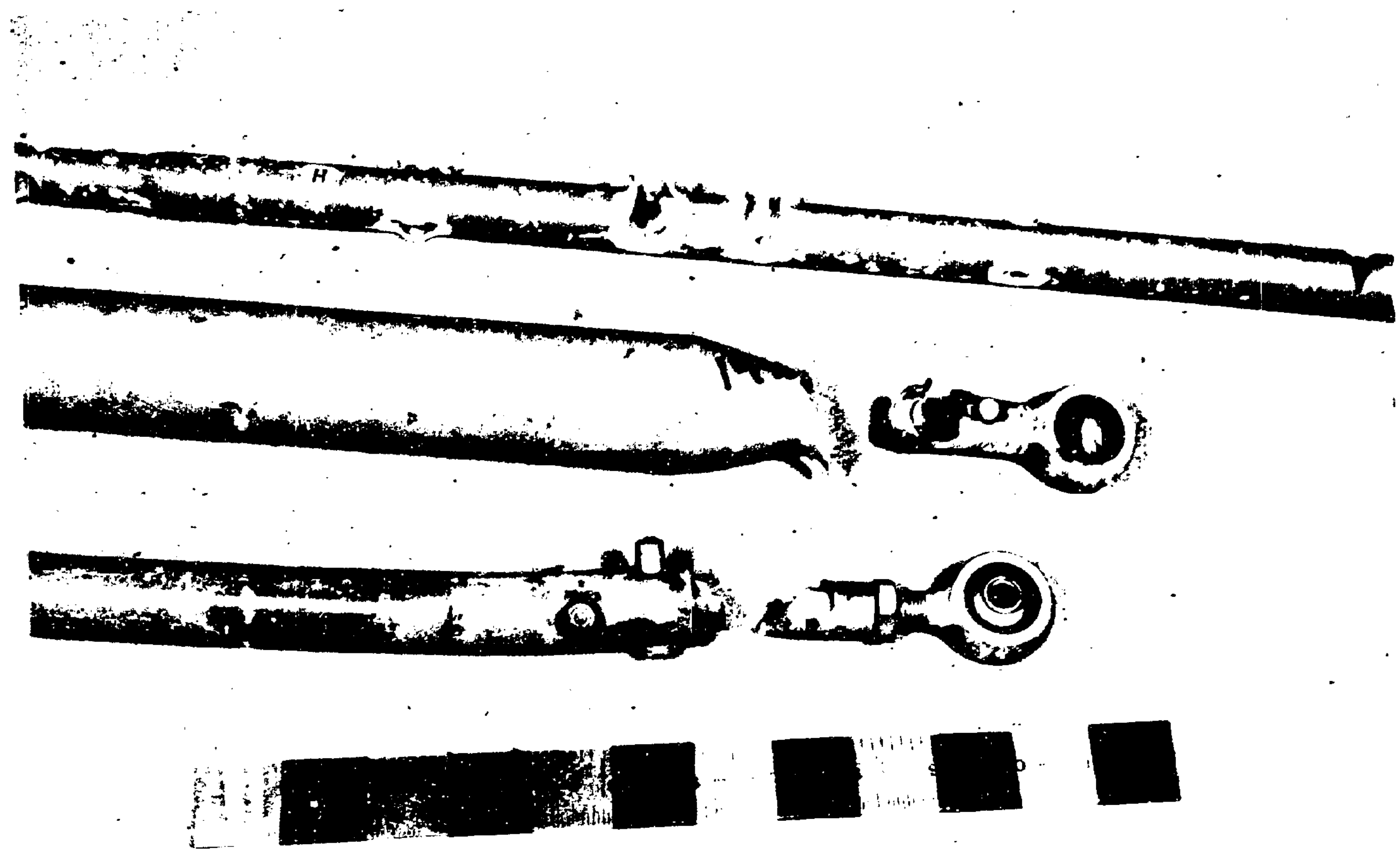


Figure 129. Control Rods.

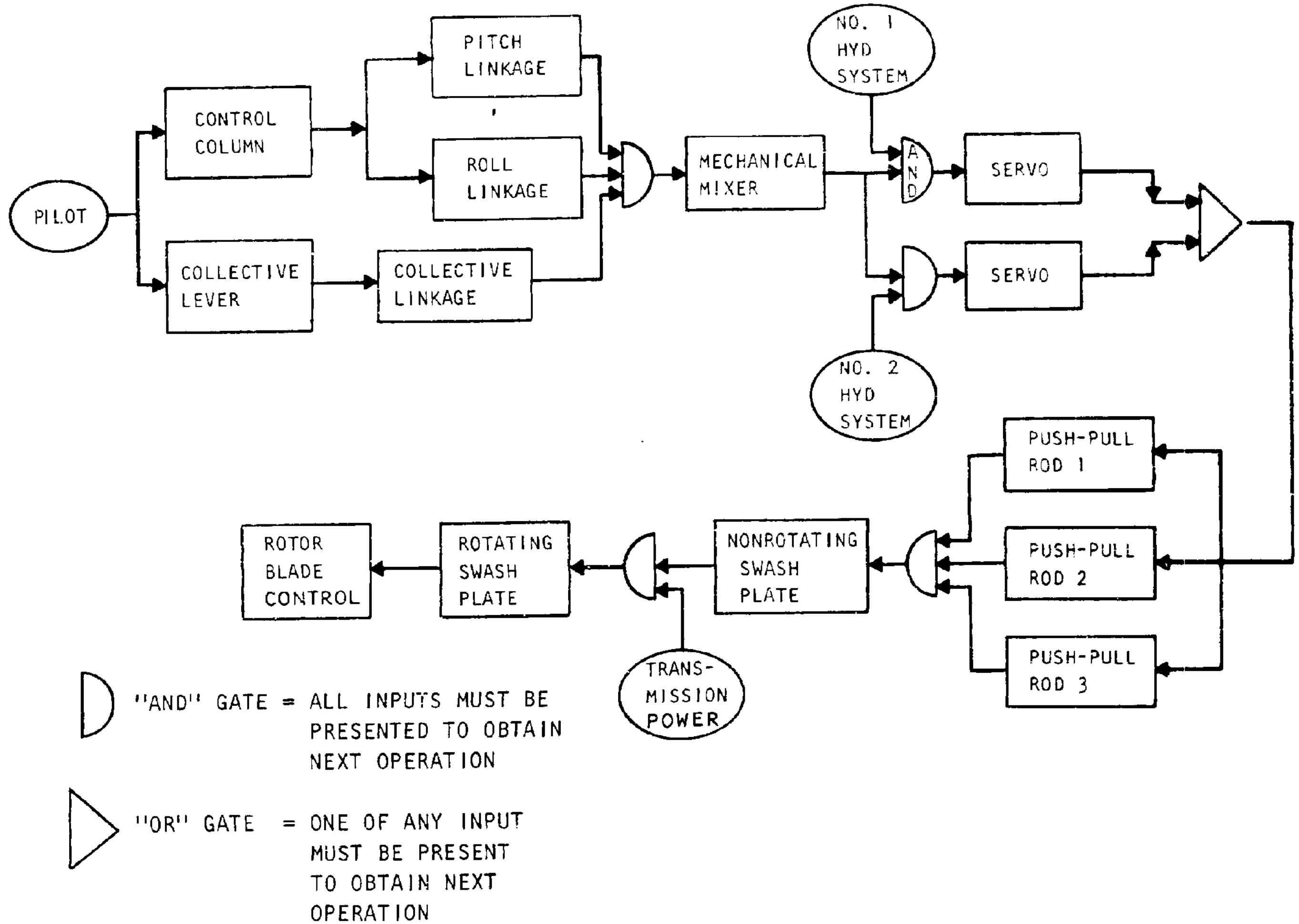


Figure 130. Pilot-to-Rotor Blade Control.

was in when the damage occurred. Each component or element in the system must be examined to consider the types of failures that may be induced by small-arms projectiles and the effects of such damage on total system operation and survivability.

4.9.3 BASIC SYSTEM CONCEPTS

Control systems are designed to activate aerodynamic surfaces by using a combination of basic system concepts. The power and response requirements for the flying qualities of the aircraft dictate to a great degree the complexity needed. While complying with the requirements for designing the total system, consideration must be given to the options available to minimize vulnerability to small-arms fire. The basic system elements are:

- Mechanical linkage systems
- Booster power systems
- Full-power systems

The mechanical linkage system may be used by itself or in combination with the powered systems, and is the arrangement conventionally used. Newer concepts may use fly-by-wire techniques to replace the mechanical linkages. The advantages and disadvantages of each must be carefully examined in regard to system survivability and operational use of the aircraft to insure that the most effective system design is obtained.

4.9.3.1 Mechanical Linkage Systems: A pure mechanical system is one in which the pilot acutates the primary flight control surfaces through a set of mechanical linkages. The system elements consist of pilot control sticks, cables, pulleys, sectors, bellcranks, push-pull rods, torque tubes, lever arms, gears, etc. For the general arrangement of mechanical linkages, the following survivability techniques shall be considered:

- Duality of mechanical linkage systems is required by Military Specification MIL-F-9490 for aircraft that may be exposed to conventional weapons. Separation of such redundant linkages should be accomplished to a practical degree that will provide mutual masking by intervening structure and equipment. The separation and masking shall consider the ballistic damage potential for the size, type, and directions of fire of enemy weapon systems that may be encountered.

- Push-pull control rod concepts are considered to have higher survivability, with small-arms fire, than cable systems where damage tolerance principles are employed.

- Cable and push-pull rod systems should be routed as closely as practical to heavy primary structure to obtain natural protection for sensitive elements and to minimize damage effects on attachments, fairleads, and structural distortions that could jam or limit the required linkage motion.

- For push-pull rod systems, consider the effect of ballistic threats on short- and long-rod concepts. Long push-pull rods can be susceptible to jamming if structure deformation or adjacent component damage is encountered. In such areas, consider the use of short-length push-pull rods with swing-arm bellcranks (idler links) as shown in Figure 131.

4.9.3.1.1 Detail Design: The detail design of mechanical control system elements is vitally important for survivability. One of the most recent and important techniques developed is that of ballistic damage-tolerant control system linkages. This concept is somewhat contrary to established methods of degrading the effect of small-arms fire. It is an approach to design components with multipath loads to accept multiple hits, yet remain functional so that the control system will permit continued safe flight. Low-density nonmetallic composite materials that allow projectiles to core out material with minimum structural damge can be used for construction. This concept minimizes the amount of kinetic energy that the projectile can impart to the component, and localizes the damage. A number of experimental control system components such as bellcranks, idler links, pulleys, and tension-compression links have been developed to reduce the vulnerability of Army helicopters. Descriptions of these and recently developed concepts are presented to acquaint the designer with the techniques that may be applied or modified to suit his particular design efforts.

4.9.3.1.1.1 CH-47 Ballistic Damage-Tolerant Walking Beam Idler Link: Figure 132 illustrates the basic construction of a fiber glass-foam core ball, socket, and support design that was developed for ballistic tolerance. It is fabricated from epxoy resin, chopped glass fibers bearing support, and surface layers of fiber glass. Figure 133 is a photograph of a test component that has been damaged by two projectiles. It was able to sustain damage that would have destroyed conventional types of bellcranks, and it was still capable of performing its function.

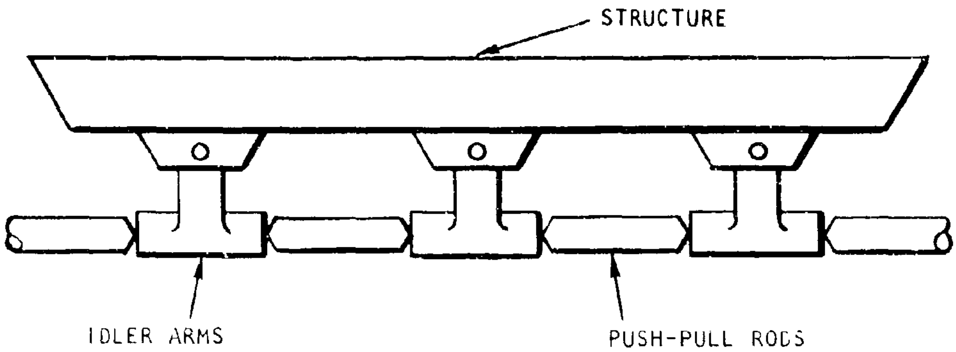


Figure 131. Short Length Push-Pull Rod Installation.

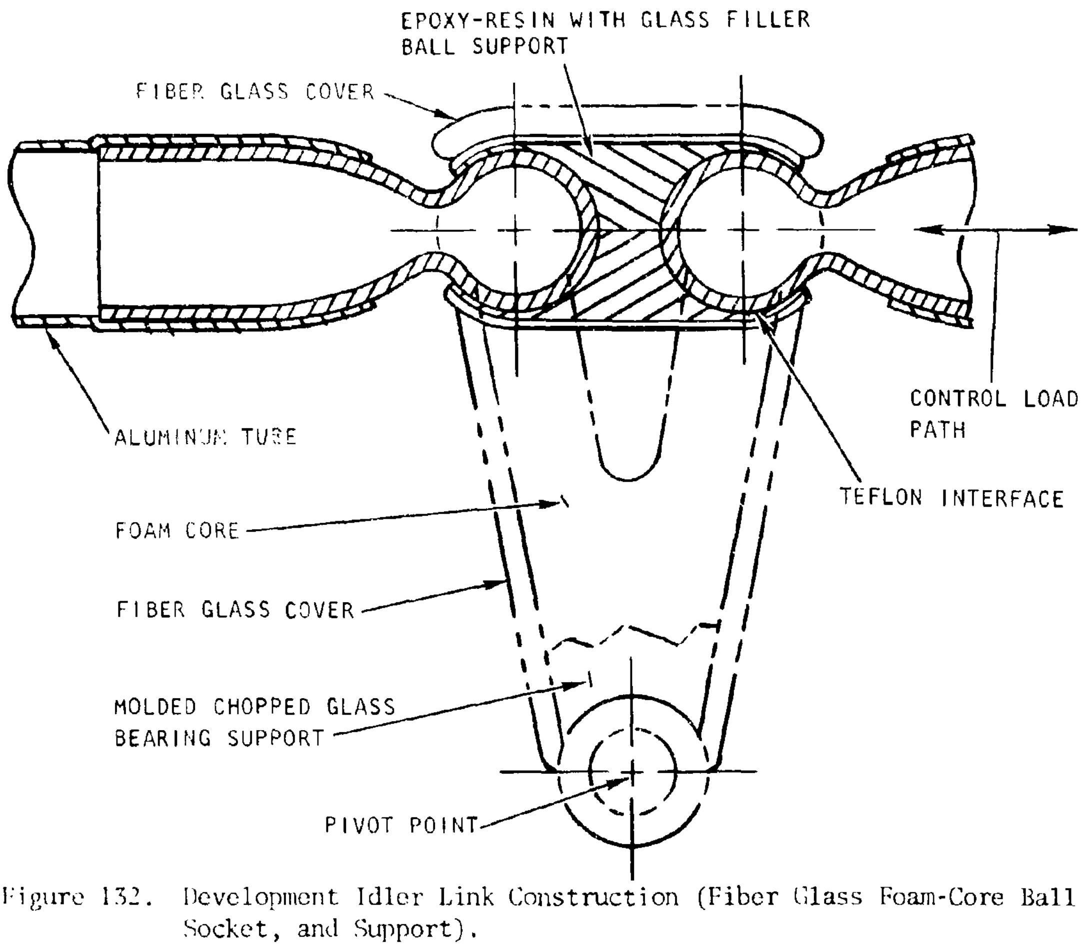


Figure 132. Development Idler Link Construction (Fiber Glass Foam-Core Ball, Socket, and Support).

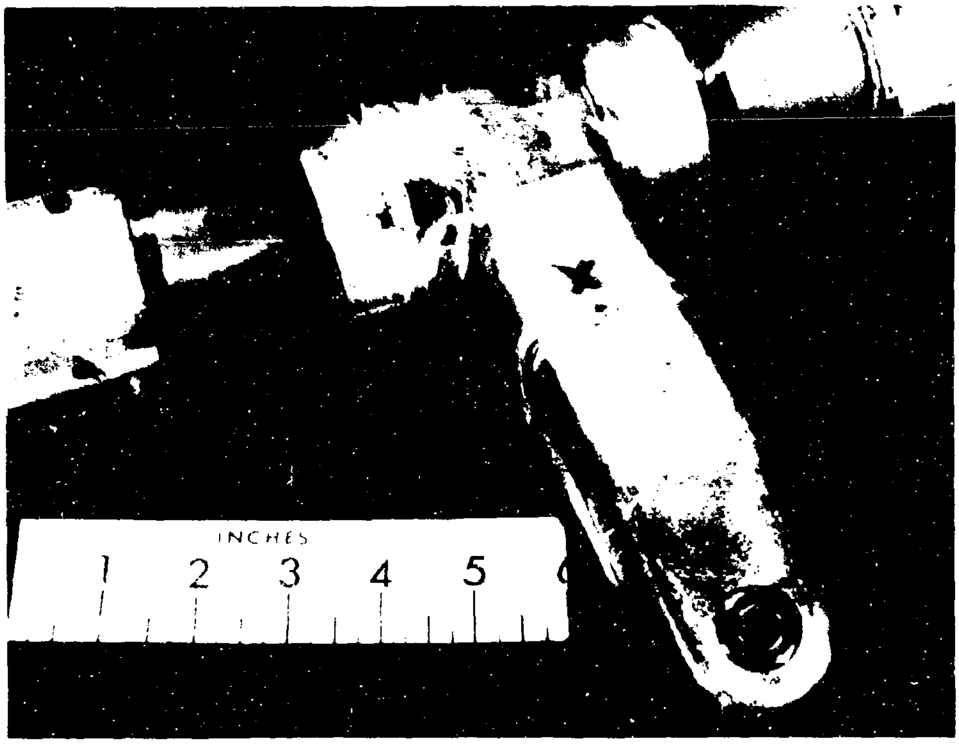


Figure 133. Experimental Idler - Link Component.

4.9.3.1.1.2 CH-47 Rotor Head Pitch Link: Figure 134 shows the original rotor head pitch link for the CH-47 helicopter, and illustrates its vulnerability to small-arms fire. A ballistic damage-tolerant experimental replacement pitch link was designed and fabricated from glass cloth and epoxy resins. This link is about 25 percent as vulnerable as the original rotor head pitch link, and that only around the bearing areas. It was subjected to multiple projectile hits as shown in Figure 135. The link was still capable of performing its design function with a limited reduction in total strength. Figure 136 shows the areas in the aircraft where the walking beam and rotor head pitch link are located.

Extensive research and development effort has been expended to develop ballistic-tolerant bellcranks for the applications shown in Figure 137 (CH-47 forward and rear pylon bellcranks). Many different approaches and configurations have been fabricated and tested. These have included sheet-metal buildup and several glass/epoxy concepts. The latter have been found to provide the most beneficial design concepts to limit damage.

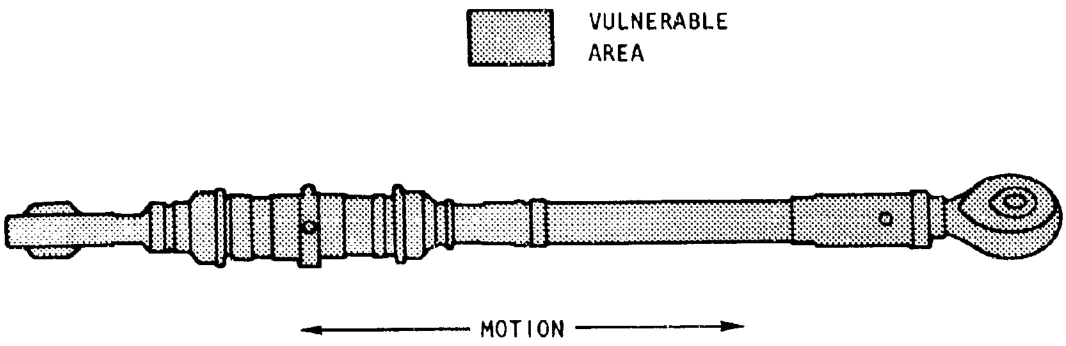


Figure 134. Vulnerability of Existing Pitch Link.

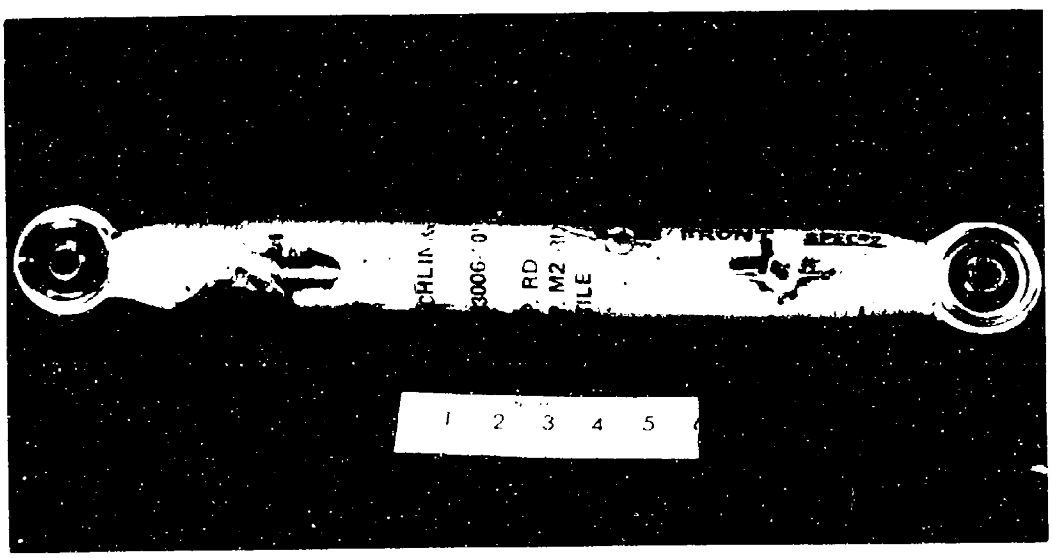


Figure 135. Ballistic Damage-Tolerant Experimental Pitch Link.

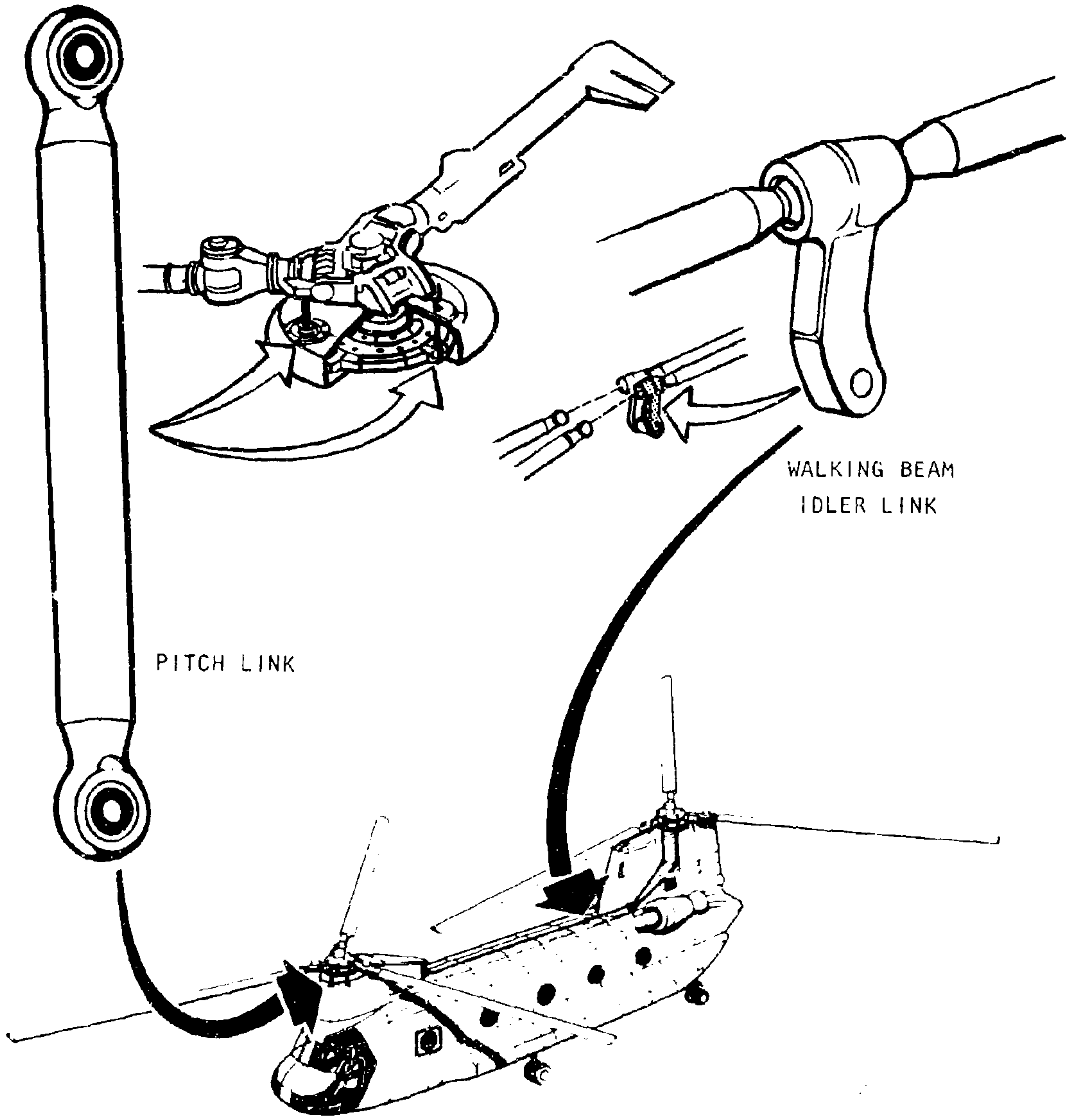


Figure 136. Ballistic Damage-Tolerant Experimental Replacement Flight Control Components.

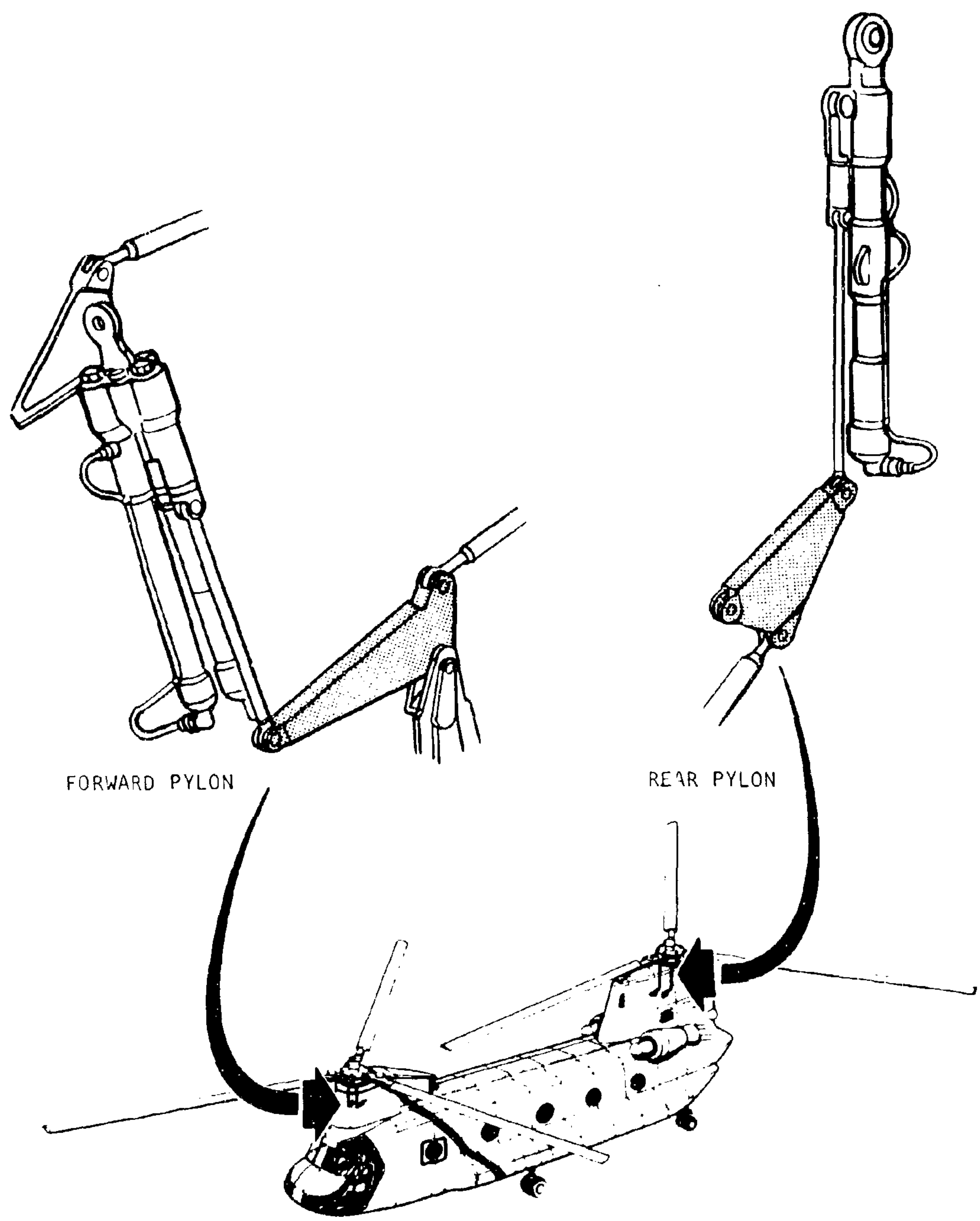


Figure 137. Ballistic Damage-Tolerant Bellcranks.

Figure 138 shows a three-dimensional space structure bellcrank concept using woven glass fibers with an epoxy covering known as "Tetra-Core." This type of construction, as shown in Figure 139, is described in Reference 80. Subsequent efforts have developed design concepts using hollow fiber glass tubing and face sheets for bellcrank designs. Figure 140 illustrates the basic principles of this construction. Ballistic tests have indicated that it is most tolerant to ballistic impacts, since there is no low-density filler material, as in honeycomb or foam designs, that tend to force delamination of the face sheets on the exit side of the projectile path.

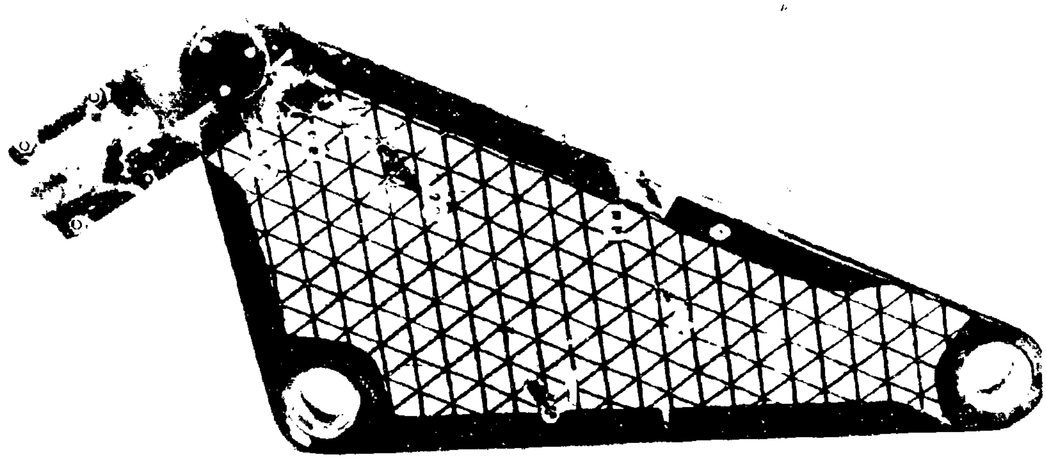


Figure 138. "Tetra-Core" Space Structure Bellcrank.

4.9.3.1.1.3 Thermal Tolerance: In the detail design of flight control mechanical elements, consideration must be given to possible exposure to high thermal conditions that may be initiated by ballistic threats. These can be short-term or low-intensity fires or rupture of hot air bleed lines. For such hazardous areas, high-temperature materials and construction techniques should be used to provide extended operational time or to prevent malfunctions or failures. For example, steel or titanium could be used for control torque tubes, brackets, sectors, etc., in place of lighter, but more vulnerable, construction materials.

THE BASIC "TETRA-CORE" ELEMENT CONSISTS OF TETRAHEDRONS WHICH ARE ALTERNATELY INVERTED AND PLACED SUCH THAT THEY FORM CONTINUOUS PLANES AS SHOWN. THEY ARE FORMED BY A FILAMENT WINDING OR LAYING PROCESS OF FIBER GLASS ROVING. AFTER COMPLETION OF THE FIBER LAYING PROCESS, THEY ARE COATED WITH EPOXY RESIN AND CURED. THEY MAY ALSO BE FORMED FROM PLASTIC SHEET OR FIBER GLASS CLOTH MOLDED TO THE DESIRED SHAPE.

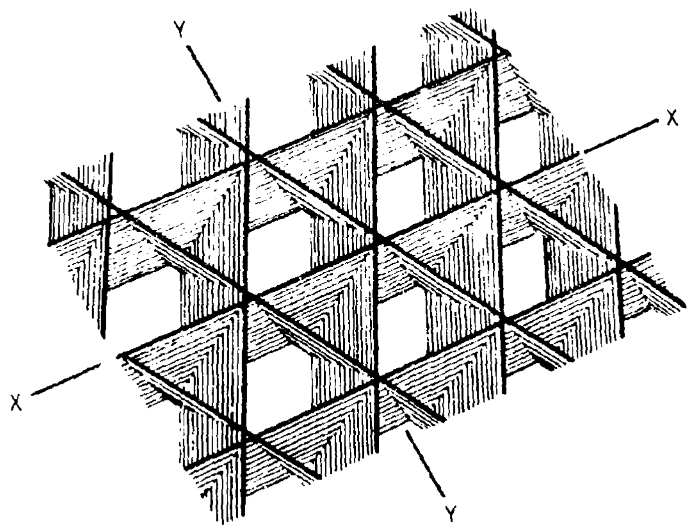


Figure 139. Basic "Tetra-Core" Element.

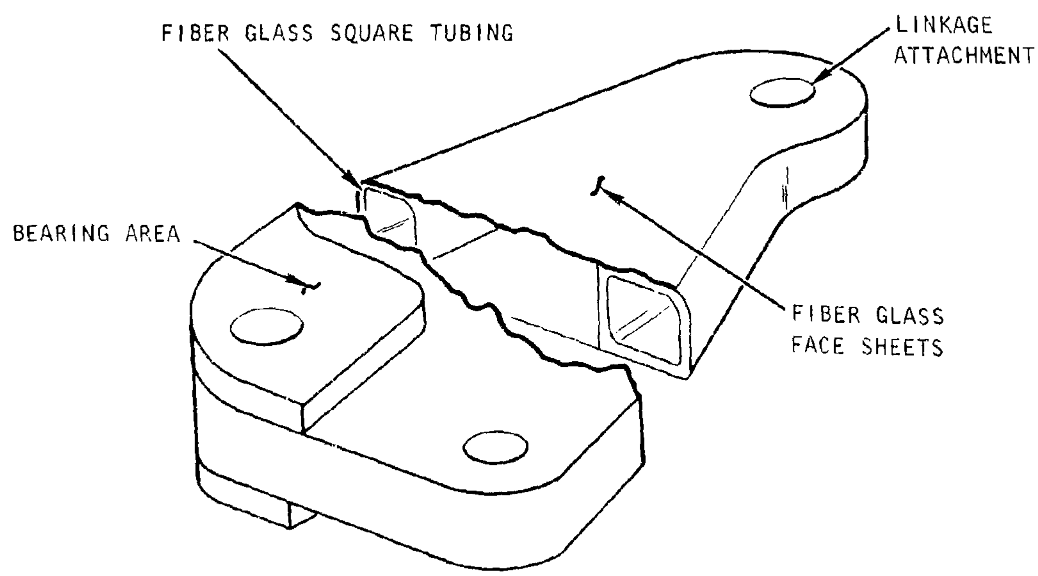


Figure 140. Ballistic Damage-Tolerant Bellcrank Design.

4.9.3.2 Powered Systems: Powered flight control systems are used where pilot strength capability is insufficient to adequately control the aircraft throughout its flight envelope. Two types of powered systems may be used: boosted or full-power. The boosted system transmits pilot actuation forces through a mechanical linkage which is amplified or "boosted" by a power source to move the control surfaces. It is a reversible load system wherein a portion of the surface forces are transmitted back to the pilot. In the event of power failure, only pilot forces are available to move the control surfaces. This type of system should be considered in favor of a full-power control system in which the pilot activates power control servo mechanisms, through mechanical linkages or fly-by-wire systems, that position the control surfaces in response to pilot position commands and are totally dependent upon hydraulic system or other power sources to maintain any control over the aircraft.

Hydraulic systems have been the primary means of providing power for military aircraft control systems in the past. They have many advantages in weight, space, and system costs. However, they are sensitive and vulnerable to small-arms ballistic damage and require careful study and consideration for new systems designs. The following are considerations that should be evaluated early in the design effort.

- Boosted or full-power hydraulic system redundancy is required by Specification MIL-F-9490. Separation and natural masking or armor should be used to minimize the probability of simultaneous failures from single or multiple projectile impacts that may be experienced from one attack direction. Separate control actuators should be used in favor of single tandem types to provide effective separation and mutual masking. Figure 141 illustrates the basic principle for a boosted power system. The sensitive actuators and power sources are arranged to provide two completely separated and redundant power sources and actuators that will provide the needed control actuation. Such boost systems should be designed to be fail-safe so that a degree of control is available to the pilot through manual effort, in the event of complete power failure, that would permit escape from the combat area and safe recovery.

  For full-power systems, the separation and mutual protection of the hydraulic power systems is even more essential, since loss of both will deny the pilot means of controlling the aircraft's flight path and result in almost certain loss of the aircraft and injury or death for personnel aboard.

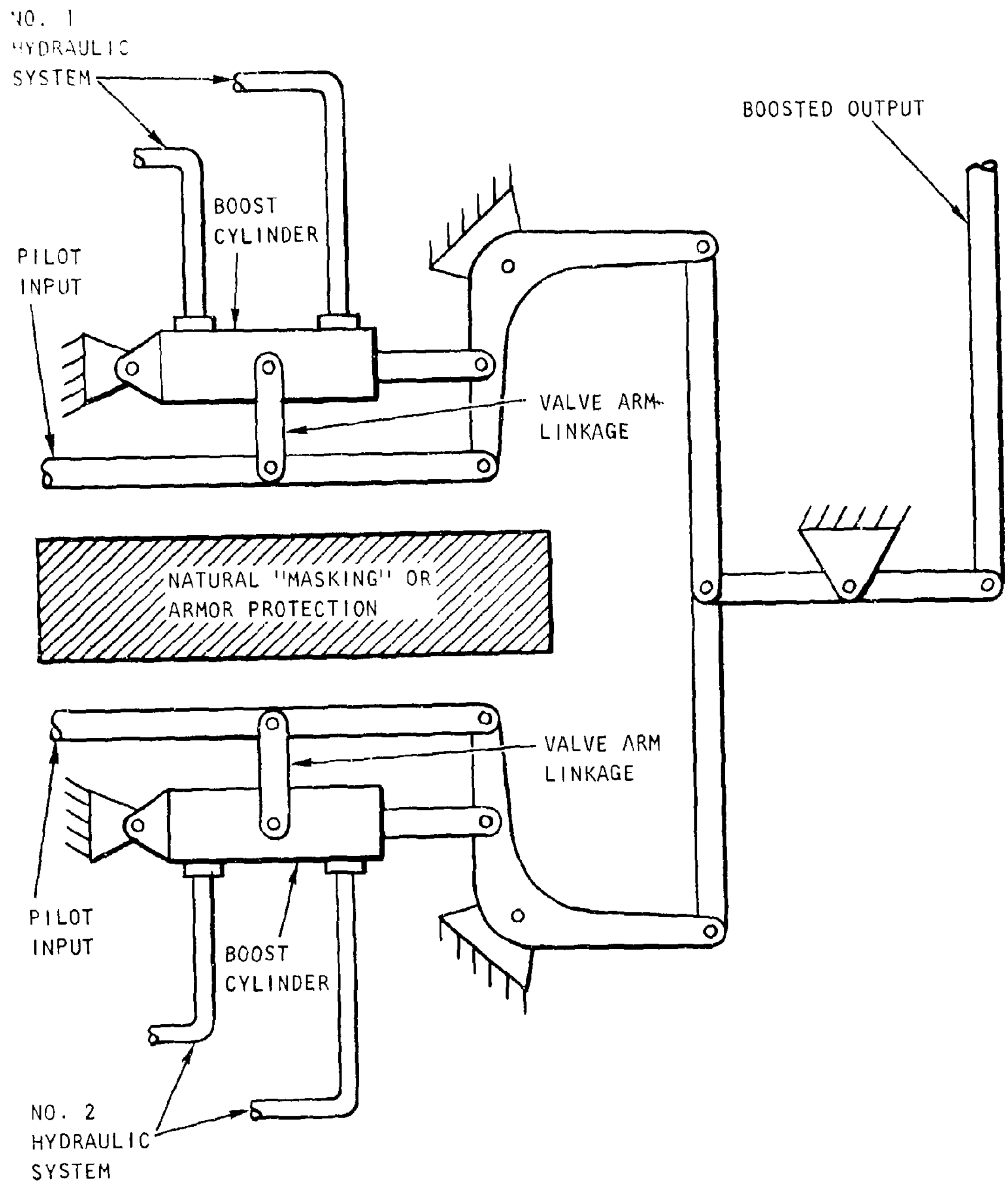


Figure 141. Redundant Boosted Control System.

- Consideration should be given to packaged hydraulic power system concepts. Hydraulic power is generated in an independent package, located close to the control surfaces, by use of electrical or mechanical power inputs. Refer to Section 4.10 for more detailed information on this technique.

- All-mechanical power sources should be considered for flight control system operation. This technique uses mechanical power, from the engine or power transmission, through rotating shafting and a mechanical servomechanism that positions the control surface in response to pilot command. A simple schematic of this concept is shown in Figure 142. This type of system can minimize secondary weapon effects hazards in that it can be relatively insensitive to spallation effects, fire, and hot-gas torching, and it does not contribute flammable byproducts when struck by projectiles.

- Fly-by-wire control system concepts have been under development for many years. This is the replacement of mechanical linkages between the pilot and the control actuator with multiple dispersed electrical signal wires that transmit control system commands. The basic principles and evolution of the system are illustrated in Figure 143.

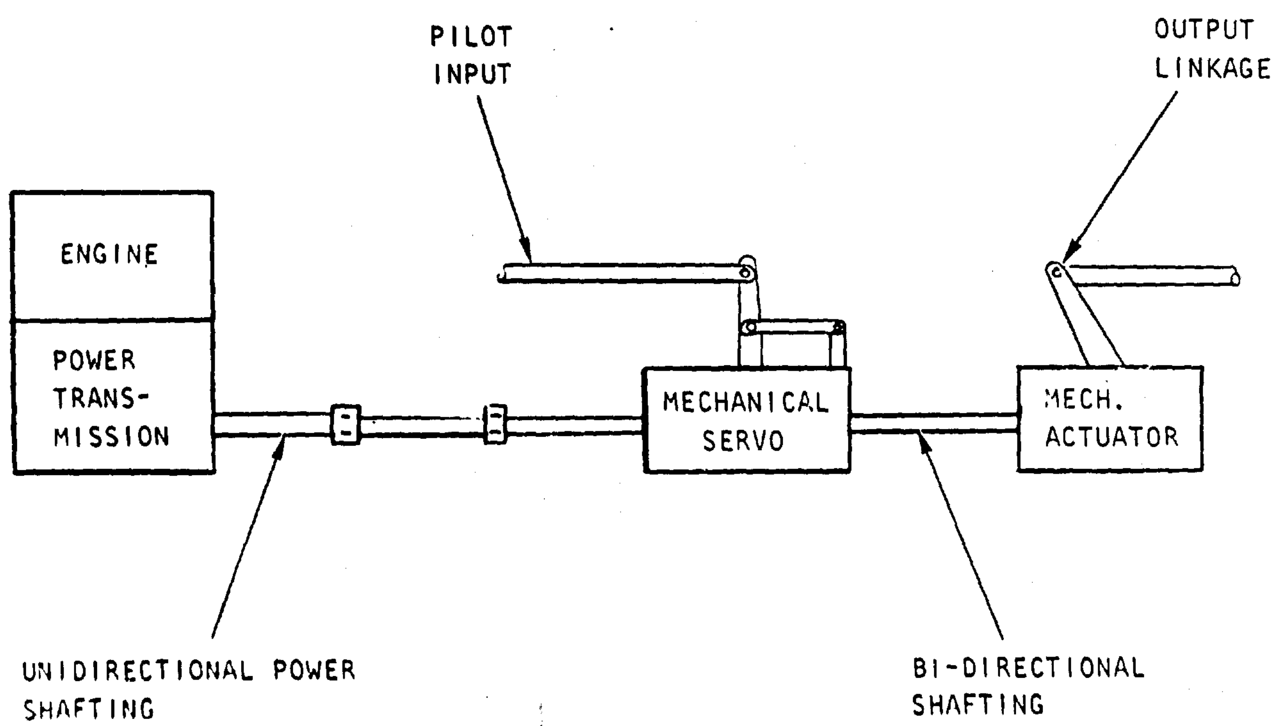
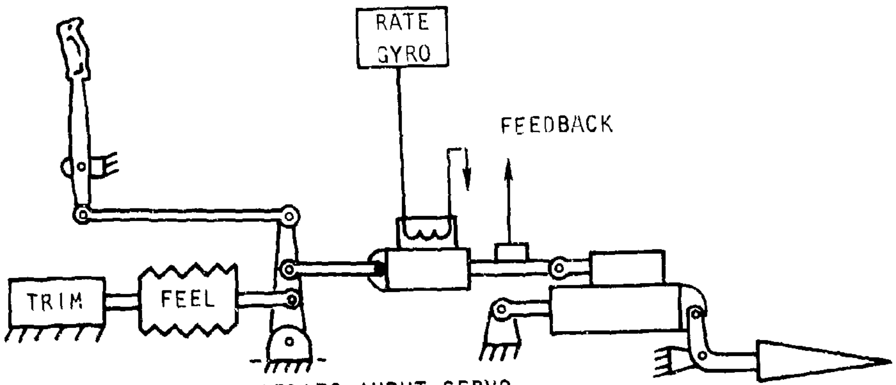
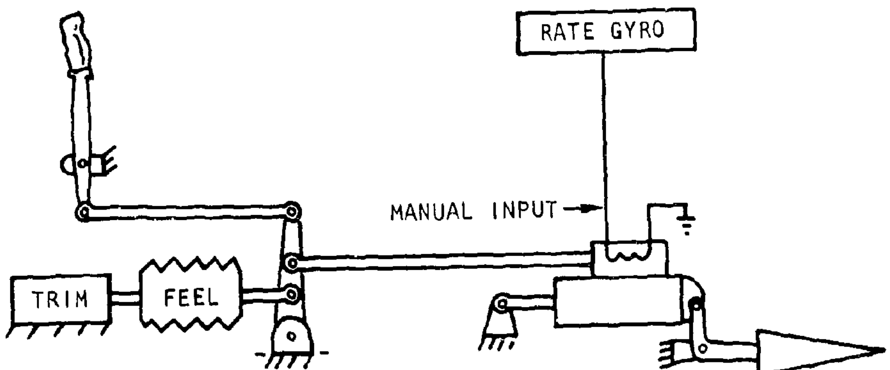


Figure 142. All-Mechanical Power System.



SERIES INPUT SERVO
(STABILITY AUGMENTATION)



DUAL VALVE INPUT
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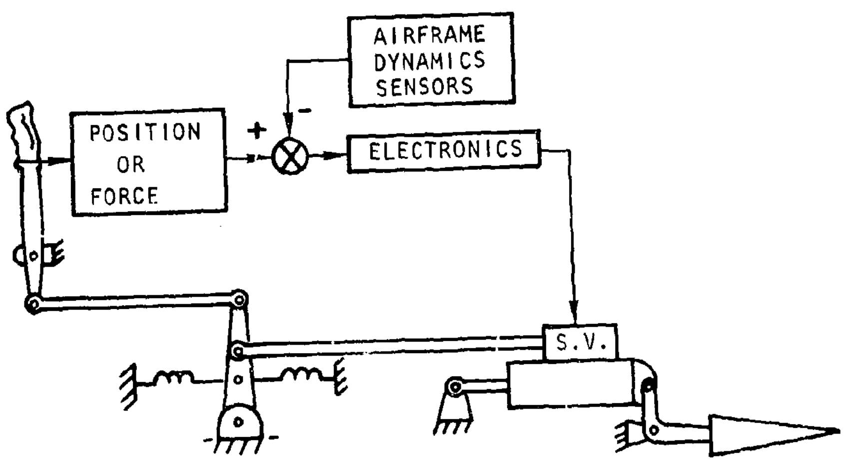

CONTROL AUGMENTATION

Figure 143. Fly-by-Wire System Concept Evolution.

Control stick motions or forces are sensed by the position or force transducer, which in turn provides an electrical signal to the electronic control box. This signal is processed in conjunction with needed airframe dynamic sensors to provide an electrical signal to the command actuator. The actuator responds to the command, and positions the control surface or element. A feedback system provides the electronic control box with the position or load information required. Multiple channel redundancy is an essential ingredient of fly-by-wire systems. This factor lends itself to potential survivability enhancement if adequate separation and mutual masking and/or armor protection of those areas considered vulnerable can be provided. Figure 144 shows the schematic for a three-channel system to control collective pitch on a two-rotor helicopter. Each has an operational, standby, and reference channel. Of primary importance in using a fly-by-wire system is provision for multiple redundant electrical power sources that in themselves are insensitive or protected from the small-arms primary and secondary weapon effects.[81]

- Fluidic systems have also been developed, during the past decade, to make use of fluid characteristics for control functions. According to the National Fluid Power Association, "A fluidic system is one in which sensing, control, information processing, and/or actuation functions are performed primarily through utilizing fluid-dynamic phenomena." This does not rule out the use of spool valves, ball valves, or other miniature control elements in which the moving mass is so small that it does not significantly affect response of the device. Use of this technology should be considered for those applications where their small size, volume, and independence of power sources, other than the operating media, can reduce the complexity and vulnerable area of the system. Fluidic servoactuators have been designed and tested for helicopter flight control applications. Figure 145 shows the basic schematic of the system. It was designed for installation as an extensible link in each of the three control axes. The function of the servoactuators is to drive the surface control boost actuator pilot valves and damp out gust disturbances imposed on the aircraft. In the absence of hydraulic system pressure, the servoactuator ram is centered and locked to provide a fixed link in the system. Recent advances in fluidic technology have resulted in significant miniaturization of the sensing and control elements. This can provide a greatly reduced vulnerable area for stabilization systems. Electronically controlled augmentation systems are dependent upon electrical power sources and sensor elements that can present larger and more sensitive vulnerable areas.[82]

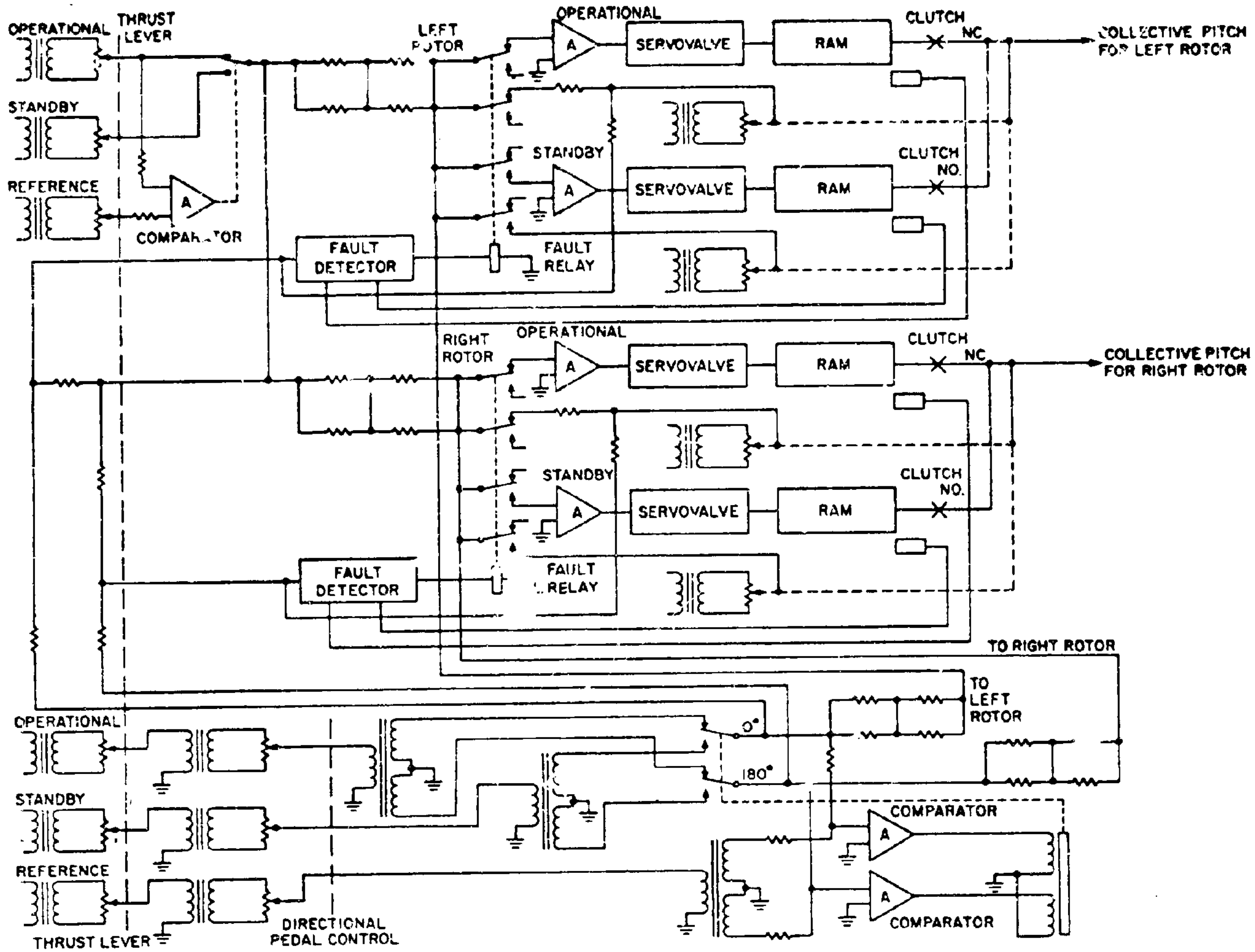

Figure 144. Three-Channel Pitch Control System.

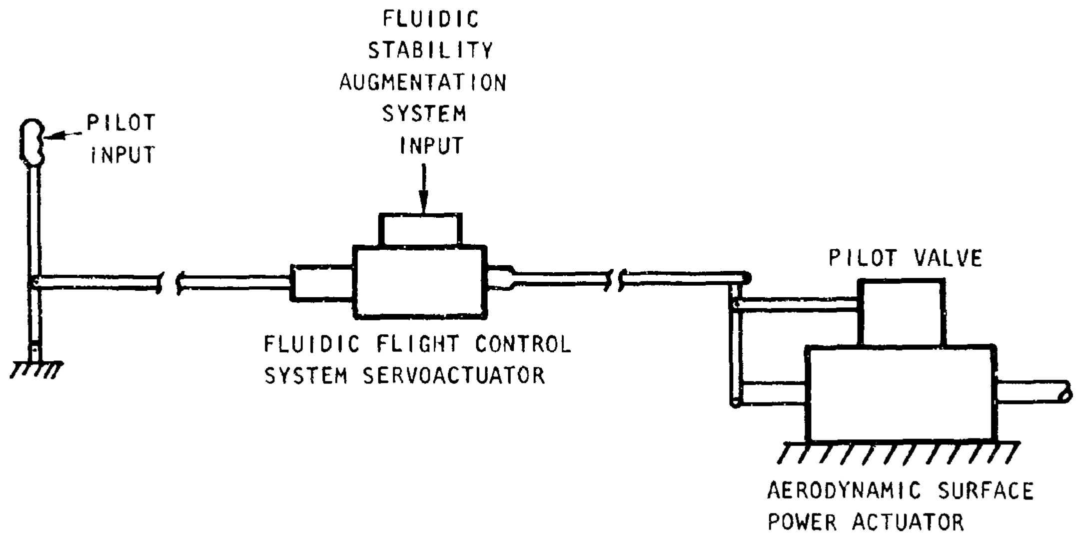

Figure 145. Primary Flight Control System Schematic.

4.9.3.2.1 Power Component Detail Design: Minimizing vulnerability of hydraulic-powered flight control system components may require the use of ballistic protection in order to prevent loss of the operating fluid, although redundancy, flow difference sensors, reservoir level sensors, and return (line) pressure sensors are also helpful.

The following are techniques that should be considered:

- Ballistic-resistant hydraulic actuators may be fabricated from metallic armor materials. Dual-hardness steel armor has been used in an actuator cylinder to defeat small-arms projectiles. Figure 146 illustrates the fabrication process of a CH-47 experimental servoactuator body from such material. Paragraph 4.10.3.2.2 discusses the fabrication and testing of an experimental ballistic-resistant actuator.[83]

- Arrangement and geometry must be considered in minimizing the actuator's vulnerability to ballistic threats. Significant benefits can be gained by locating the control valve and sensitive linkages on the side of the actuator away from the most probable direction of hostile gunfire. Figure 147 shows a representative configuration of a control system actuator with sensitive areas located in a favorable position. This provides natural masking protection for the elements shown, and presents the most favorable geometry of the cylinder to minimize projectile penetration. Remaining critical

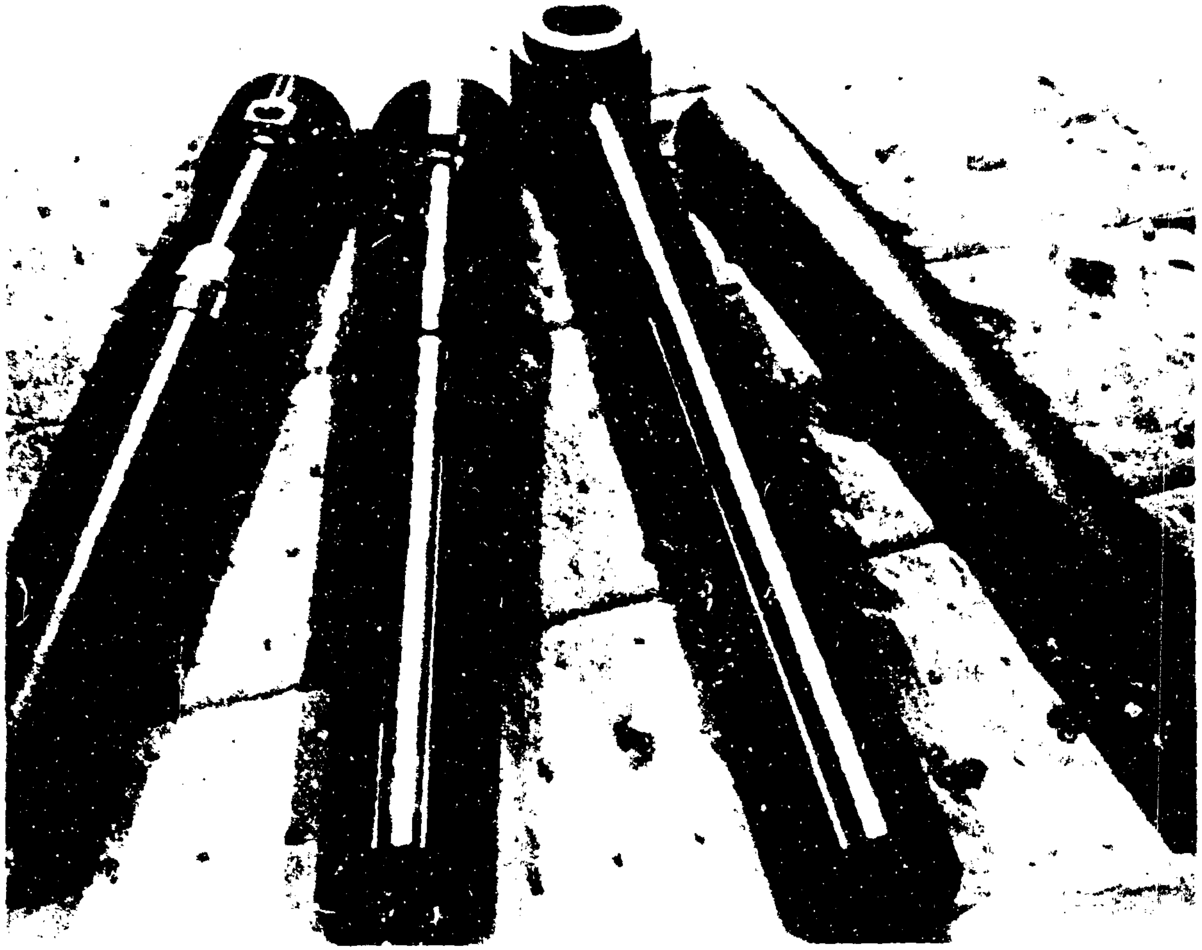

Figure 146. CH-47 Experimental Servoactuator Body Fabricated From Dual Property Steel Armor.

areas which are still vulnerable should be protected by armor shields. The cylindrical shape is the most efficient for obtaining obliquity angles to the threat projectile for even distribution over the total presented area of the actuator. As shown in Figure 148, the angle of obliquity increases as the line of impact moves away from the cylinder centerline and the line normal to its major axis.

4.10 FLUID POWER

4.10.1 INTRODUCTION

The use of fluid power for aircraft-essential subsystem operation increases as the size and/or performance of the system grows. Flight control systems, for example, require more power than the pilot can produce when aerodynamic loads exceed certain values. Other subsystems (i.e., landing gear, armament, secondary controls, etc.) also become dependent upon power sources to perform their required functions. Fluid power consists of hydraulic and pneumatic systems. Hydraulic systems have been used almost exclusively for such functions in military aircraft since the inception of required force augmentation. Pneumatic power, on the other hand, has not been used to any significant extent. Its use has been generally limited to secondary subsystems where "two-position" actuation (extend-retract) was required. Because of aircraft losses in combat resulting from hydraulic system failures, considerable attention has been directed, during the past decade, toward improving the survivability of hydraulic systems against ballistic threats. Little effort has been directed toward similar improvements in pneumatic systems, since their damage and/or failure has not contributed to aircraft losses. Most of the survivability enhancement techniques contained in this section, therefore, are for hydraulic systems. As for all design techniques, the penalties and benefits for each must be carefully considered for both initial design and operational aircraft modification efforts.

4.10.2 BALLISTIC DAMAGE EFFECTS

Small-arms ballistic impacts can create a variety of damage mechanisms that would destroy or degrade the capabilities of fluid power systems. These possibilities must be evaluated in the design process in order to insure that the most practical and effective combination of survivability features is incorporated into the system. Hydraulic and pneumatic subsystems have different responses to ballistic weapon effects, as described in the following paragraphs.

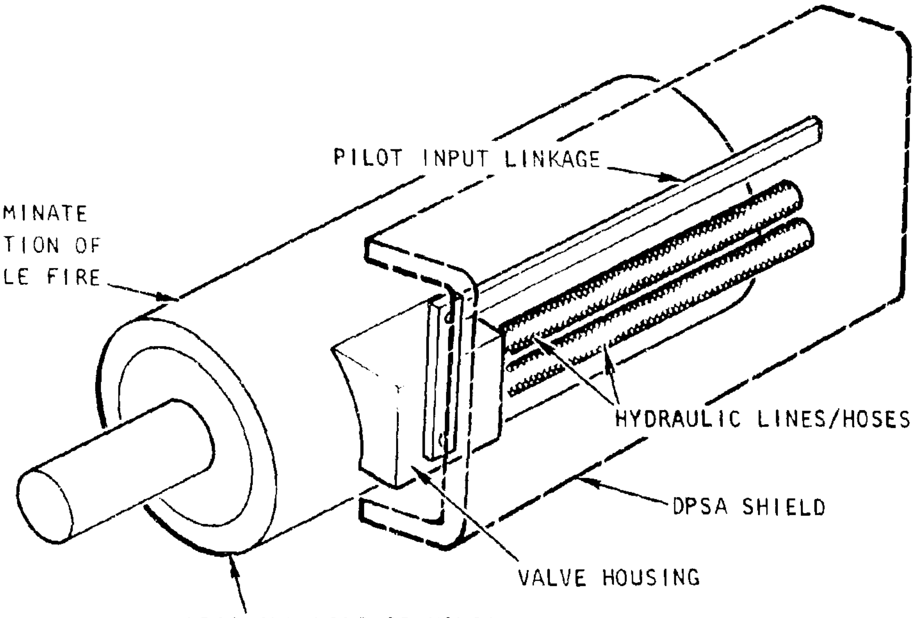

Figure 147. Favorable Actuator Arrangement.

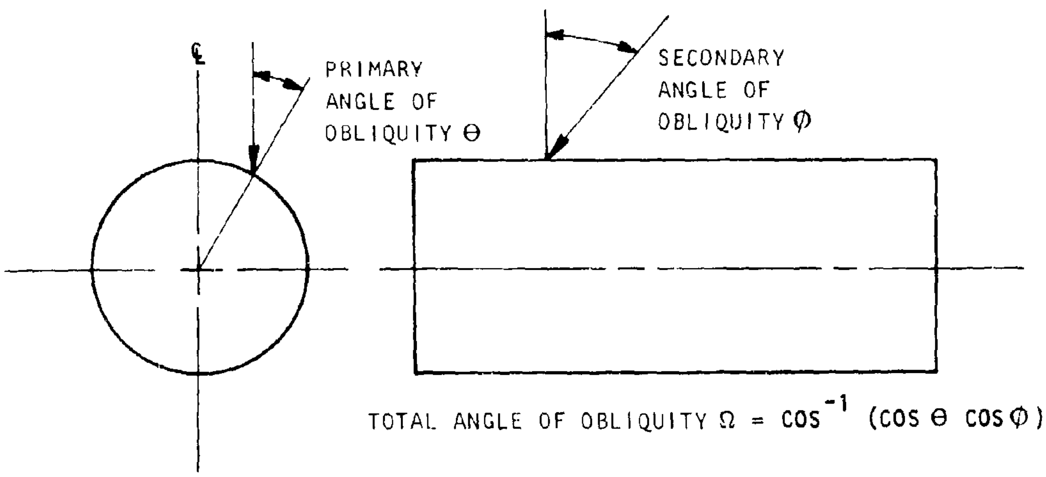

Figure 148. Angle of Obiliquity.

4.10.2.1 Hydraulic System Response: The major hydraulic system damage mode, from projectile impact, is leakage of the operating fluid from components or lines. The major effect of the leakage is depletion of the system fluid supply and pressure available for component operation. A secondary effect is liberation of a fluid which, depending upon its characteristics, may be ignited by a projectile's incendiary characteristics or other ignition sources, thus resulting in a hazardous fire condition. Other damage modes can include deformation of hydraulic components or lines that does not result in leakage but causes restriction or blockage of the return line, which may cause a "hydraulic lock" condition. This would "freeze" the actuator in that one position and destroy its ability to perform its designated function. High thermal conditions may be generated by small-arms weapon effects (i.e., fuel, lubrication oil, other flammable materials fires, or damaged hot air-bleed systems) that may be capable of causing failures of hydraulic system components or lines. These failures, in turn, may cause loss of essential subsystem capabilities. Smoke or toxic fumes may also be generated by ignition or heating of hydraulic fluids, which, in turn, could affect the capabilities of the aircrew to perform their assigned duties. Penetration of high-pressure vessels, such as accumulators and shock struts, by projectile impacts may cause explosive disintegration of the unit, which, in turn, may cause secondary fragments to be generated that could be capable of inflicting personnel injury or damage to other vulnerable systems. Damage modes and effects for each essential and nonessential hydraulic system should be analyzed to insure that primary and secondary vulnerabilities are not overlooked. Figure 149 shows a simplified schematic of a hydraulic circuit. The basic elements of a hydraulic system serving flight- or mission-essential and nonessential subsystems are shown. The primary and secondary weapon effects from small-arms fire must be evaluated for each hydraulic system component and element to determine its response and effect upon the aircraft's survivability. This analysis serves to identify system vulnerabilities to which survivability enhancement techniques may be applied.

4.10.2.2 Pneumatic System Response: Pneumatic systems are susceptible to the same basic ballistic damage mechanisms as the hydraulic systems. The responses are somewhat different, however. Leakage from pneumatic-operated systems can be tolerated to some degree, since the operating medium (gas or air) is continuously being supplied and is not dependent upon a fixed volume. The compressed gas energy in pneumatic system components provides a potential explosive-type hazard if the container disintegrates or shatters when struck by a projectile. The temperature of the pneumatic operating medium can also pose a secondary hazard to other nearby essential subsystems by "hot torching" effects or generation of high-pressure conditions in other equipment such as hydraulic system accumulators. Hot

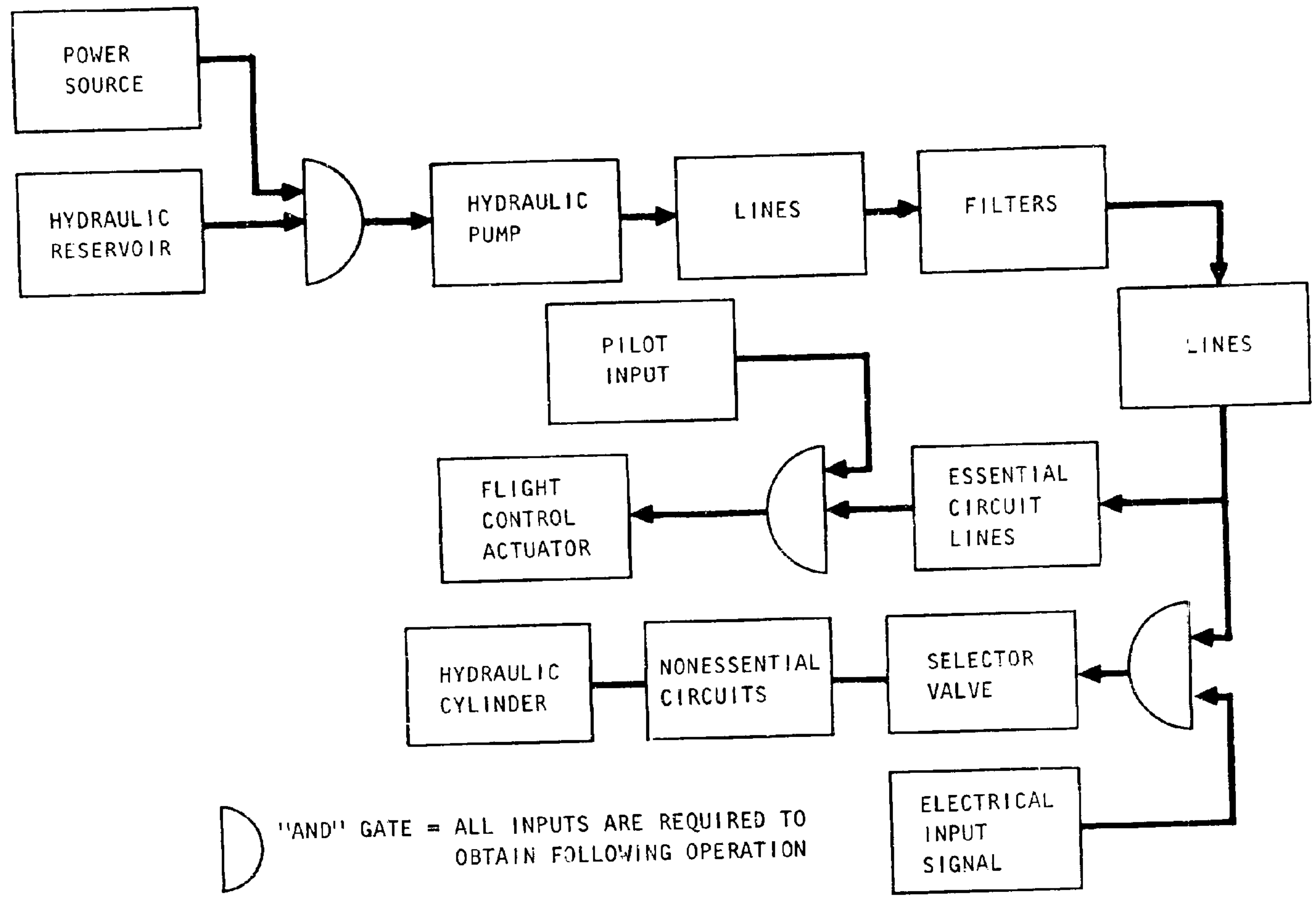

Figure 149. Representative Hydraulic Circuit.

gases may also provide an ignition source for flammable materials liberated by prior, concurrent, or subsequent small-arms fire. The hot gases may also create a direct hazard to the aircrew or passengers by impinging upon their occupied space, or by generation of smoke or toxic fumes.

4.10.3 HYDRAULIC SYSTEMS

4.10.3.1 System Considerations: Survivability must be considered during the development of the system circuitry and its general arrangement in the aircraft, including the selection of power sources, isolation of essential circuits, masking or armor-shielding sensitive areas, and selection of the operating hydraulic fluid. All of these considerations must be evaluated against the rest of the aircraft design requirements as well, to select the most appropriate combination of survivability features. The following techniques should be considered.

4.10.3.1.1 Fluid Medium Selection: MIL-H-5606B hydraulic oil is the most commonly used by existing military aircraft. It can be readily ignited by small-arms incendiary projectiles or by other ignition sources when liberated. More sophisticated hydraulic fluids have been developed in recent years that exhibit reduced flammability characteristics. They have penalties associated with them in terms of cost, availability, special seal elastomer requirements, and impact upon operational logistics if introduced into Army aviation inventories. Table XXV contains a listing of candidate hydraulic fluids together with data on flash points, auto ignition temperatures, and ranking for comparative safety. Selection of a fluid must be made on evaluation of all factors involved, particularly the configuration of the aircraft and other techniques to prevent and/or suppress hydraulic system fires.

4.10.3.1.2 Circuit Design Factors: Redundancy of flight control hydraulic systems is required by Specifications MIL-H-5440 and MIL-H-8891. Where other mission-essential functions are dependent upon hydraulic system power, redundant and physically separated systems should be considered to minimize the probability of aircraft loss or mission abort. Critical circuits should be arranged to minimize the size and complexity of the systems that can be exposed to small-arms fire. Noncritical segments of the hydraulic systems should be isolated from the essential systems by pressure-line shutoff valves and return-line check valves to minimize vulnerable areas and the volume of fluid that could be liberated and become a potential fire hazard. Figure 150 illustrates the basic principle of this technique. Ranking of the priority of each set of components powered by a specific hydraulic system should also be considered. The system reservoir, pump, and necessary accessories (i.e., filters, accumulators, pressure transducers, etc.) should be located as

TABLE XXV. HYDRAULIC FLUID FLAMMABILITY COMPARISON

Fluid Type	Flash Point (° F)	Auto Ignition Temperature (° F)	Increased Safety
Hydrocarbon			
MIL-H-5606B	190	475	
MIL-H-27601A	375	700	
MIL-H-83282	410	700	
Silicate Ester	420	760	
Phosphate Ester			
Low-Density	340	1,000	
High-Density	550	925	
Polyphenyl Ester			
5-Ring	550	1,135	
Silicone			
Fluoropropylmethyl	430	850	
Methylchlorophenyl	550	900	

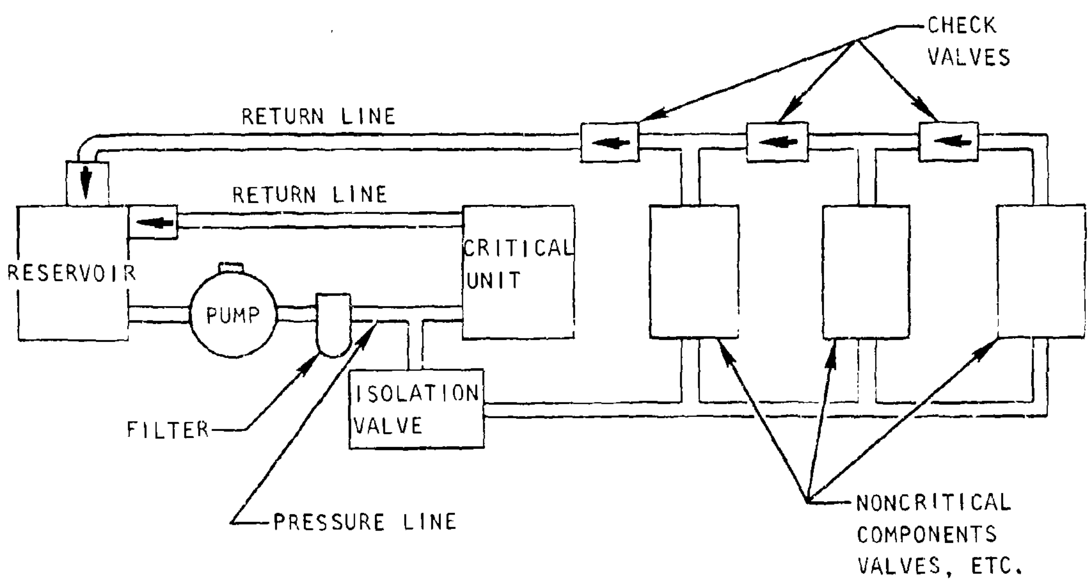

Figure 150. Hydraulic Circuit Considerations.

close as practical to critical components to minimize vulnerable areas exposed to hostile gunfire. The location of the system should consider material masking features to the greatest extent practical, and armor applications for sensitive areas that cannot be protected in any other manner. The isolation valve should be fail-safe to the closed position, in event of electrical power disruption, but it should also be evaluated for emergency operation in noncombat or recovery portions of the mission where actuation of the noncritical components (i.e., landing gear extension) may be required for system safety requirements.

4.10.3.1.3 Pulsating Hydraulic Systems: Research and testing feasibility studies have indicated that a "pulsating" or ac-type of hydraulic system can provide a less vulnerable power source for critical or mission-essential components. The basic principle of such a system is shown in Figure 151. This arrangement shows a three-line pulsating system. A variable-delivery hydraulic pump provides continuous pressure and flow to an alternator valve driven by a separate motor. The alternator delivers a pulse of hydraulic pressure to each of the three transmission lines through individual diaphragms that separate the pump system from the lines. The pressure pulses pass through a transformer unit designed to magnify the system pressure. They then pass through a rectifying valve to provide positive pressure to the actuator.

The system is designed so that it can sustain ballistic damage to a transmission line without loss of the essential component operation, but this fact has yet to be verified. As long as one transmission line remains intact, a degree of operation, at reduced rate, is retained. In contrast, with a conventional continuous-flow system, damage to either the pressure line or the return line will result in loss of component operation and, depending upon the circuitry, in loss of the entire hydraulic power system. As can be seen, a weight penalty is associated with this type of system that must be carefully evaluated against other means to protect a conventional hydraulic power system.[84]

4.10.3.1.4 Integrated Actuator Packages: An integrated actuator package (IAP) is essentially a self-contained hydraulic system that operates at the point of control surface actuation. It consists of an electrically driven motor, hydraulic pump, reservoir, valving, and accessory equipment. Electrical power is supplied by the aircraft's electrical power generating sources to the electrical drive motor. This technique is also referred to as a hydraulic packaged power concept, as shown in Figure 152. Redundant power supply lines should be considered for such applications. The system concept can be considered both for normal operation of an actuator or as a separate emergency power system

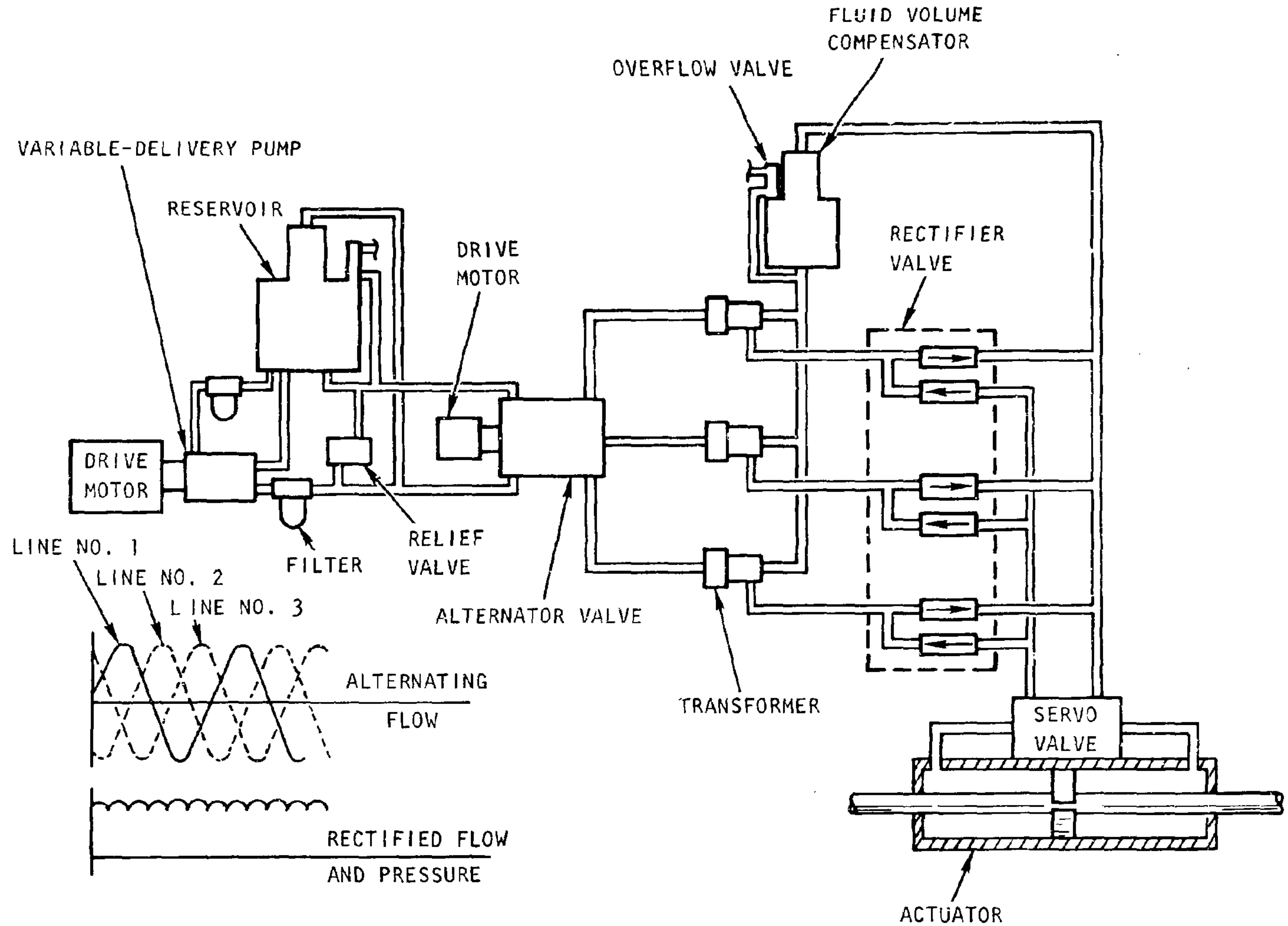

Figure 151. Three-Line Pulsating System.

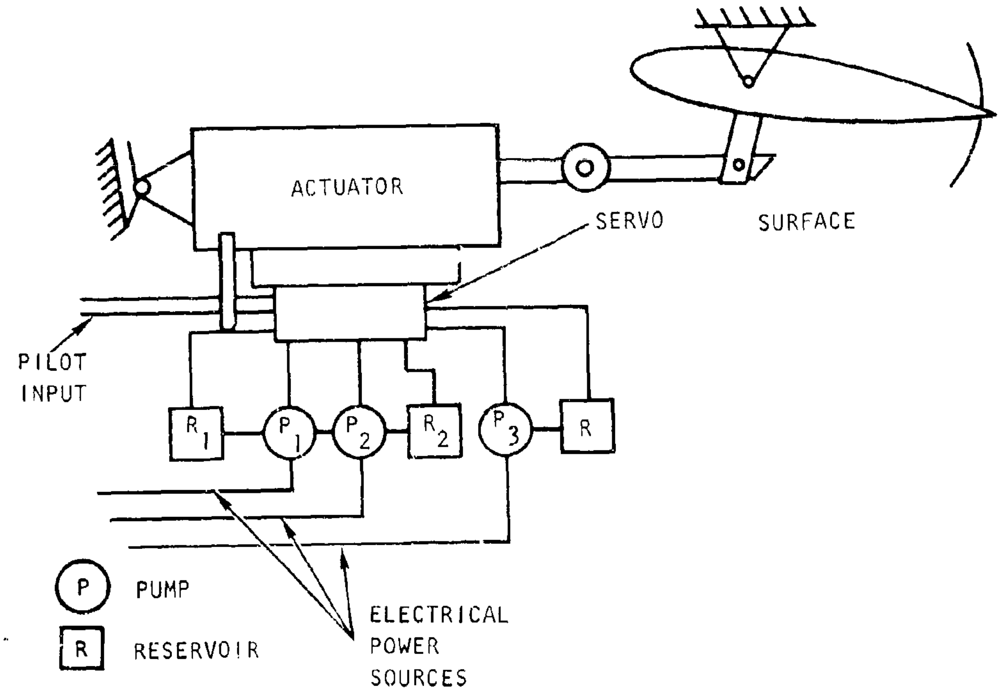

Figure 152. Hydraulic Package Power Concept.

designed to recover the aircraft, with limited operating capability if the primary power source is lost. The electrical power source vulnerability and the possible weight penalties associated with the concept must be carefully assessed.[32]

4.10.3.1.5 Fire/Heat Tolerance: Hydraulic systems are susceptible to failure from fires or high-heat conditions that may be initiated by small-arms fire. A significant increase in system survivability, or extended operational capability to permit controlled recovery or forced landing, can be realized by techniques that prevent or delay hydraulic system failures. Steel hydraulic lines should be used for both pressure and return lines in area where fires or high-heat conditions can occur. Coiled tubing should be used in place of hoses where line flexure is required in the hazardous areas. Conventional hydraulic line connecters are prone to loosening and leaking when exposed to high temperatures. They should be located away from the potential hazard areas. Most important is providing a degree of flow through the lines to essential system components. This acts as a heat sink that prevents or significantly delays line failure that could otherwise occur if no flow is present.

4.10.3.1.6 Leakage Isolation: Recent research has resulted in the development of devices to sense leakage or pressure loss of hydraulic fluid in a circuit and automatically isolate the hydraulic pressure line in that portion of the system. One such unit is known as a flow difference sensor. Figure 153 illustrates the application of the device in a critical flight control hydraulic system circuit. The flow difference sensors are located in areas removed from potential damage areas. In the event of ballistic damage to the lines or the actuator that results in a given leakage rate, the flow difference sensor automatically shuts off the hydraulic pressure flow to the actuator. This prevents failure of the hydraulic system itself so that it is still able to operate other or more critical units it is designed to service. The operational principle of the unit, as shown in Figure 154, uses two sets of orifices to create pressure drops across two areas, giving two forces proportional to flow. These forces are applied to a summing lever assembly so that equal forces (correct flows) balance each other out. An unbalance of the forces causes the lever assembly to move. This allows the shutdown spool to move to the right, cutting off the pressure-line

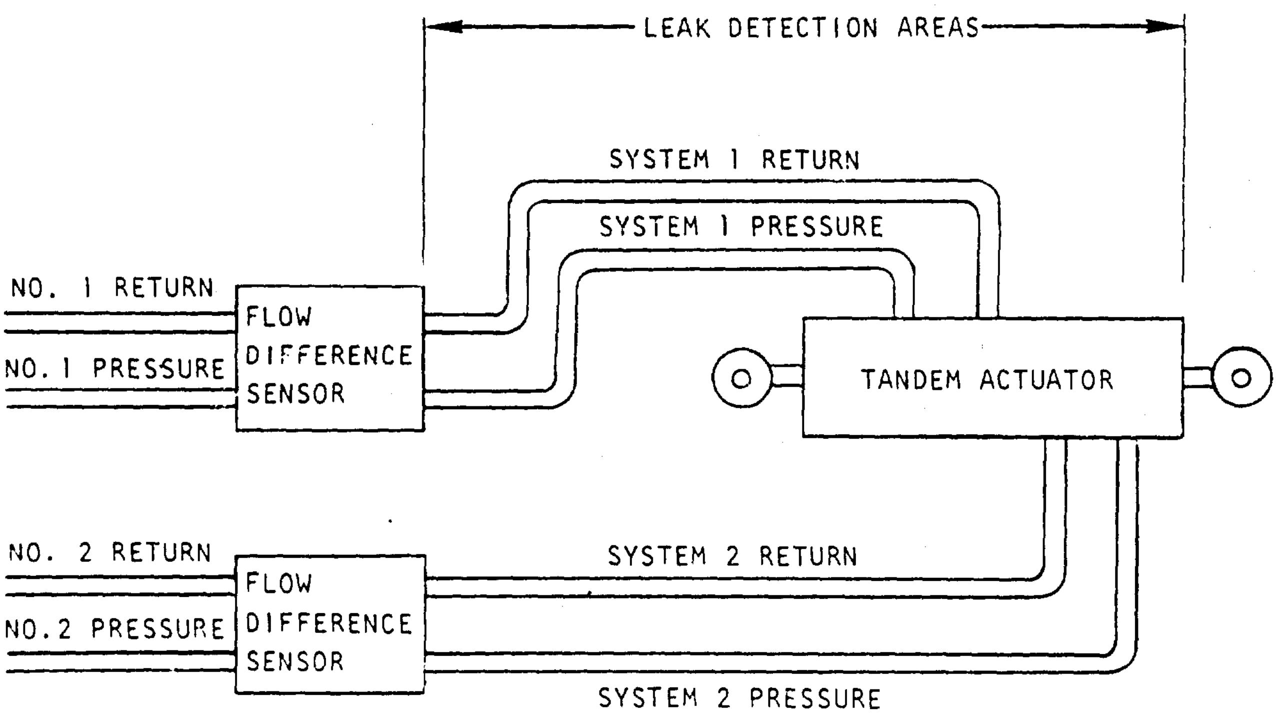

Figure 153. Flow Difference Sensor Application.

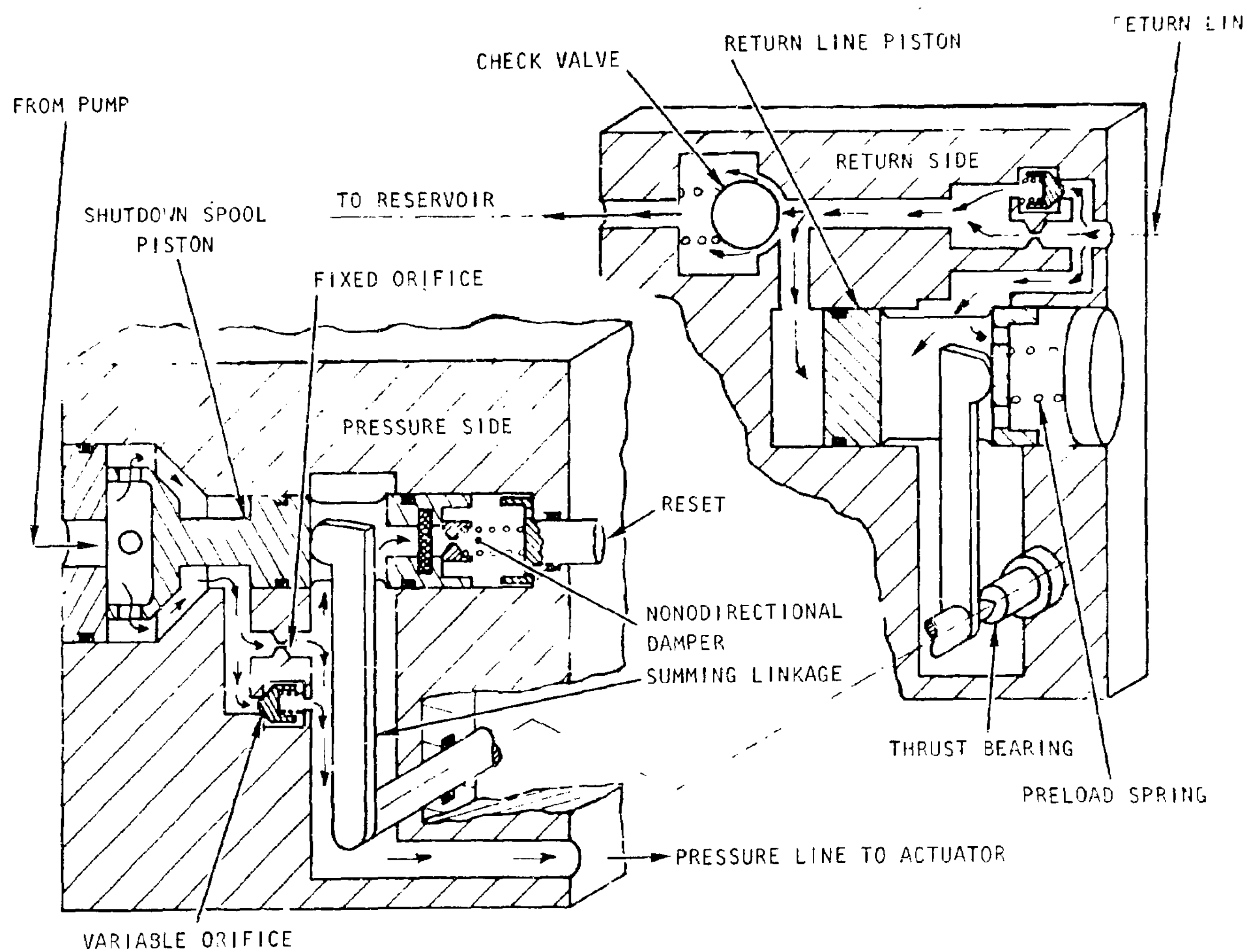

Figure 154. Flow Difference Sensor.

flow to the actuator. Once the shutdown spool has cut off the pressure-line flow to the actuator, the pump pressure at the left end of the shutdown spool keeps it in the shutoff position.

A check valve is used to prevent reverse flow when supply flow is shut off. A preload spring, loading the summing lever in one direction, is used to establish a leakage flow detection threshold. To obtain a reasonably linear pressure-to-flow relationship with minimum temperature sensitivity, it is necessary to use sharp-edged orifices in a staging configuration. For low flows, a small orifice is used. As the flow increases, a second, larger orifice is opened up. A monodirectional damper is incorporated in the right end of the shutdown spool. This damper delays the shutdown long enough so that the normal transmission line delay characteristic between pressure and return line transient flow does not cause shutdown. A reset button is incorporated to allow resetting of the unit manually after it is tripped.

Reservoir level sensor (RLS) systems have been developed to detect the loss of hydraulic fluid quantity in a system reservoir and shut off the pressure to a damaged circuit. This circuit isolation technique is used to retain integrity of the hydraulic power system for essential functions in other portions of the system's circuits. The basic principle of the technique is shown in Figure 155. The hydraulic reservoir has a shaft with an integral cam that extends when the fluid level is depleted. The cam mechanically actuates pilot valves as it travels passed them. When the No. 1 pilot valve is actuated, it directs system pressure to shutoff valve No. 1, causing it to go to a closed position. This isolates circuit No. 1 from the hydraulic system pressure supply. The pilot valve remains in the actuated position after the shaft cam has travelled beyond the initial actuation point. If circuit No. 1 had sustained battle damage, then by isolating it from the pressure supply system, the loss of hydraulic fluid would be stopped, and the reservoir fluid level shaft would not continue to extend. If the damage is in circuit No. 2, then shaft extension would continue until pilot valve No. 2 would be actuated. This would direct system pressure to the shutoff valve that would isolate circuit No 2. At the same time, a mechanical interconnect between the two pilot valves would position pilot valve No. 1 back to its initial position and allow the shutoff valve for circuit No. 1 to reopen.

Each of the shutoff valves contain a position and pressure transducer switch that is used to provide the pilot with hydraulic circuit condition information.

In conjunction with reservoir level sensor systems, the use of return pressure sensor (RPS) devices has been investigated. This type of system

monitors the pressure of the return side of an essential circuit. If the return side pressure falls below a minimum value, it provides a signal to an RLS system, which prevents switching of system pressure into that specific circuit that would result in additional loss of hydraulic system fluid.

4.10.3.2 Detail Design Considerations: Hydraulic systems are composed of many different types of components. They include pumps, actuating cylinders, filter assemblies, accumulators, valves, pressure switches, gauges, servo valves, etc. The following techniques should be considered in the initial design process to select the most beneficial one for the specific application.

4.10.3.2.1 Material Selection: Construct components from materials that will resist failure from cracking or shattering when struck by a projectile or spall. This technique is particularly applicable to low or unpressurized components such as reservoirs, where a degree of system capability would be retained if the damage is contained within those limits that still permit the unit to hold the minimum amount of hydraulic fluid for system operation. Figure 156 illustrates the basic principles of the concept. The selection of nonbrittle material also serves to limit the amount and rate of flammable fluid that would be liberated and minimize secondary spallation hazards to nearby sensitive components.

4.10.3.2.2 Ballistic Resistance: Consideration should be given to the integral construction of units from ballistic-resistant materials such as dual-hardness steel armor. The material serves two purposes: (1) to defeat the ballistic threat, and (2) to perform its operational function. Figure 157 shows an experimental servoactuator unit for the CH-47, with the cylinders fabricated from DPSA. Care must be taken in this design to select the proper thickness of DPSA, not only to defeat the projectile threat but to preclude any internal dents of the cylinder wall resulting from projectile impact. Where such construction is not feasible and ballistic protection must be provided, parasitic armor, shaped to provide the most effective coverage, should be considered and can also be used in conjunction with integral armored components to protect remaining critical vulnerable areas. Figure 158 shows a CH-47 servoactuator unit protected by a parasitic armor shield fabricated from dual-hardness steel. In conjunction with the above technique, the incorporation of flow passages within the main body of the unit should also be considered, rather than the use of external hydraulic lines that are highly sensitive to projectile and secondary fragment damage.[85,86]

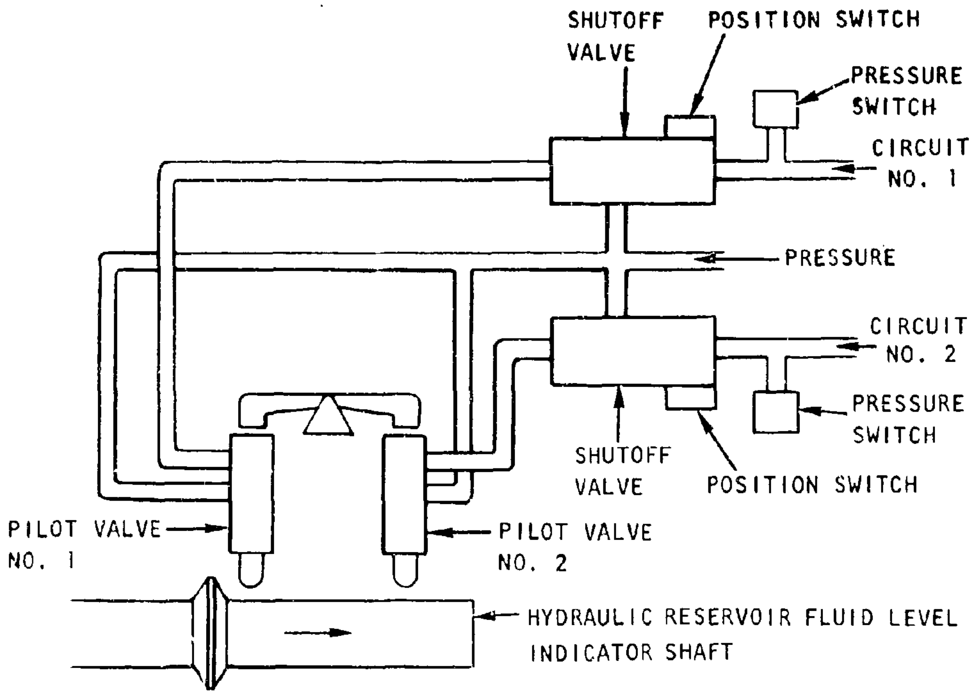

Figure 155. Reservoir Fluid Level Sensing.

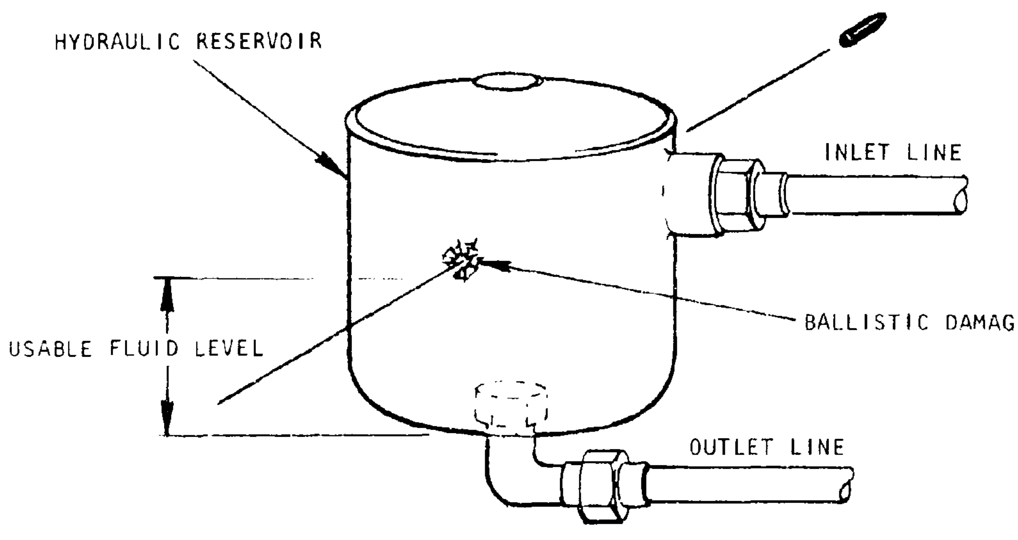

Figure 156. Ballistic Damage-Tolerance Applic[illegible]ion.

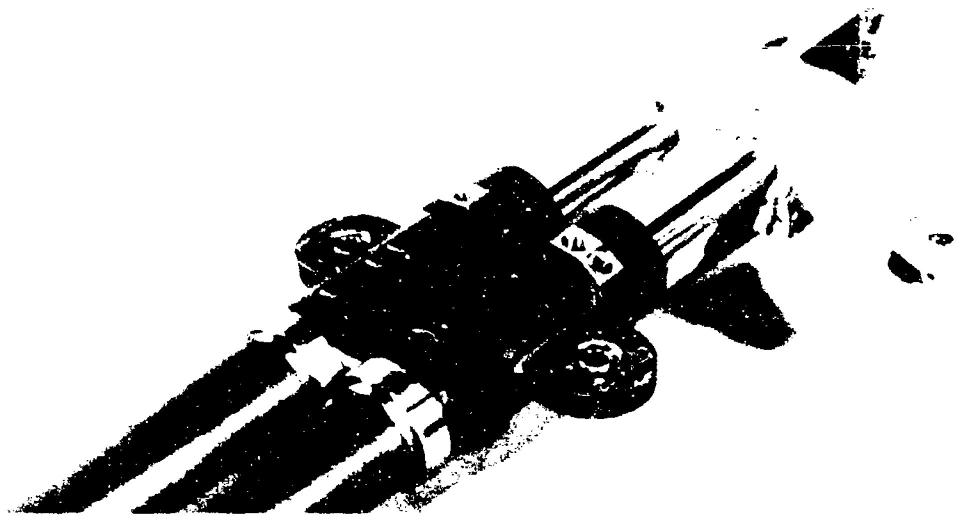

Figure 157. CH-47 Experimental Servoactuator Unit With Integral DPSA Cylinder.

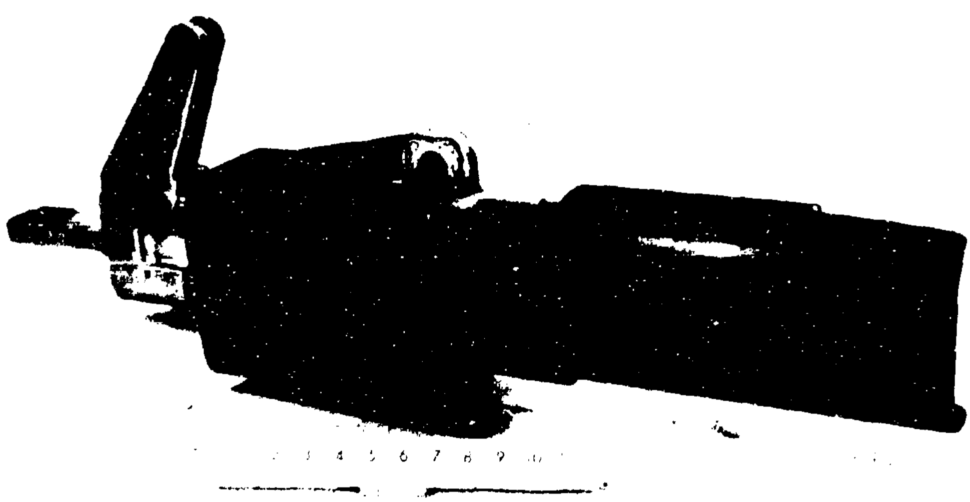

Figure 158. CH-47 Servoactuator Unit With Parasitic DPSA Shield.

Another technique for providing a level of ballistic resistance is to incorporate a steel cylinder sleeve within an aluminum cylinder body to act as a deformalite barrier to preserve the integrity of the hydraulic power system. Figure 159 illustrates the concept. Ballistic tests have shown that some steel sleeve deformation from projectile (.30 caliber) impact could be sustained and still retain system operation.[32]

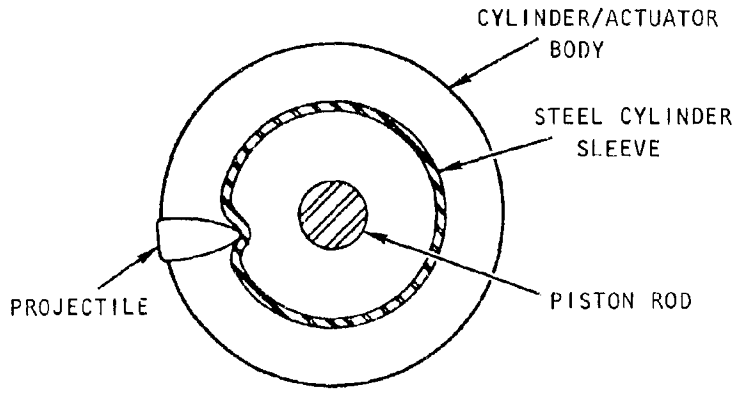

Figure 159. Cylinder Steel Sleeve Barrier.

4.10.3.2.3 Miniaturization/Integration: Vulnerable areas of hydraulic systems are the sum of vulnerable sections of each component and the hydraulic lines connecting them. Significant reduction of such areas is possible by miniaturization of the units and/or integration of the units into packages that can more easily and effectively be protected. The use of higher pressure hydraulic systems (4,000 versus 3,000 psi) would enhance miniaturization of actuator sizes. However, care should be taken to assure that surface stiffness and flutter conditions are met. Integrated actuator packages would also enhance use of higher system pressure and eliminate some hydraulic lines. Combinations of filters, selector valves, pressure transducers, etc., have been designed for improved maintenance and accessibility benefits that can complement survivability enhancement features as well.

4.10.3.2.4 Thermal Tolerance: Where essential hydraulic components are located in areas where short-term fires or high-temperature conditions may be generated by small-arms fire, metallic static and dynamic fluid seals should be used to prevent or extend time to failure. A degree of internal fluid flow should also be provided to prevent or prolong

burn-through and failure. The flow passages should be located on the side of the unit away from the most probable line of hostile weapon fire.

4.10.3.2.5 Hydraulic Line Installation: Route essential hydraulic lines along heavy portions of aircraft structure, with shortest practical length, to obtain the best masking against the probable directions of hostile weapon fire. Redundant hydraulic lines should be separated to prevent multiple power loss from a single projectile impact. A distance of 18 inches between systems is considered advisable for small-arms threats.

4.10.4 PNEUMATIC SYSTEMS

4.10.4.1 Pneumatic Systems Function: Pneumatic systems are generaly utilized for secondary subsystem operation or as emergency backup systems to secondary hydraulically powered subsystems, such as landing gear and wheel brake systems. The potential secondary hazard effects of high-pressure pneumatic systems when damaged by ballistic weapon effects must be considered. Penetration by projectiles or spallation is the major kill or damage mechanism for such systems, since extremely high energy may be released and cause major aircrew, airframe, or subsystem damage.[32]

4.10.4.2 System Considerations

4.10.4.2.1 Fluid Medium Selection: Selection of the pneumatic medium is chiefly limited to compressed atmospheric air, nitrogen, or turbine engine bleed air. Basic aircraft considerations usually dictate this choice, unless the high temperature of engine bleed air is found to be more hazardous than mechanically compressed air, and this factor may outweigh other penalties.

4.10.4.2.2 Circuit Design: Critically consider survival enhancement during the initial or modification design phase by applying the following techniques that are suitable for the specific circuit:

a. Design basic pneumatic circuits to minimize size and complexity of the system area vulnerable to ballistic weapon effects. Provide pressure-line shutoff valves or devices to isolate nonessential circuits during exposure of the aircraft to hostile weapons.

b. Use automatic failure and shutoff systems to prevent or limit secondary failures that could occur from weapon effect damage.

4.10.4.3 Detail Design Considerations

4.10.4.3.1 Components: These include compressors, reservoirs, actuators, cylinders, filters, moisture removal elements, gages, valves, pressure regulators, etc. Consider using the following techniques to minimize malfunction or prevent failure from weapon effects:

a. Construct high-pressure components to resist explosive disintegration when struck by projectiles or fragments to prevent or minimize structural or other subsystem damage from the released gases or fragments from the component.

b. Design component attachment lugs to fail, instead of component critical sections, when the component or structure is subjected to blast or other deformation loads because of hostile weapon effects.

4.10.4.3.2 Lines/Hoses: Select pneumatic lines and hose to resist damage or failure when subjected to deformation, fire, or high-temperature torching effects. Consider repair and replacement penalties for various types of pneumatic line configurations such as standard flared or flareless tube connecters, and brazed or welded line fittings. Quicker and easier repair of combat damage with standard connecters may be preferred over lower weight penalties of brazed or welded systems.

4.10.4.3.3 Installation: Consider primary and secondary damage mechanisms because of weapon effects upon pneumatic power equipment and distribution systems. Use the following techniques to minimize system malfunction or to prevent failure when subjected to weapon effects:

a. Route essential or critical pneumatic lines close to heavy structure to obtain the most natural shielding from projectiles or fragments as practical, as well as the least structural deformation induced damage from weapon effects.

b. Separate redundant pneumatic lines as far as practical, while providing natural or armor shielding to prevent or minimize simultaneous damage and or failure from multiple fragment or spallation weapon effects.

c. Provide pull-away clips or frangible clamps to allow pneumatic lines to remain intact if attaching structure is deformed by weapon blast effects.

d. Keep critical pneumatic line lengths as short as practical to minimize their vulnerable area.

e. Use frangible sections of structure where pneumatic bulkhead fittings are attached, to minimize line failure due to structural deformation from weapon effects.

4.11 ARMAMENT SYSTEMS

4.11.1 INTRODUCTION

An armament system provides for the transporting, aiming/sighting, arming, launching, and terminal guidance of weapons. The major classifications of weapons are bombs, missiles, rockets, guns, and chemical/biological dispenser systems. The system may also include active defense systems to enhance mission completion and aircraft survival by suppressing or destroying the hostile force's weapon effectiveness.

4.11.2 DAMAGE EFFECTS

Successful ordnance delivery requires the proper operation of the armament system while exposed to hostile weapon effects. The design criteria and suggestions are directed at general and specific requirements for enhancing the survivability of the armament/weapon delivery systems of U.S. Army aircraft when exposed to small-arms fire. The information presented on ammunition and larger stores can also be applied to ordnance being shipped via transport aircraft.

When impacted by bullets or fragments, a wide range of reactions of ammunition stored onboard an aircraft can be expected, including sustained fires that are capable of causing secondary cookoff-type reactions.

There are several related questions to be answered when assessing the vulnerability of targets containing large amounts of high explosive (HE) ammunition to fragment or bullet impact:

- How does one round react when subjected to fragment or bullet impact?
- When one round reacts explosively to fragment or bullet impact, what effect does it have on adjacent rounds?
- What types of reactions are required to achieve an unacceptable level of damage to various types of containers for the ammunition?

Once the threat has been defined, the first two questions can be answered independent of a given container or storage configuration. Testing may indicate that single rounds or groups of rounds are not vulnerable to bullet or fragment impact, and do not increase the vulnerability of the ammunition containers. Conversely, testing may indicate that one round

will react explosively to bullet or fragment impact, and that this explosive reaction will cause all remaining rounds in the container to react similarly. This will usually result in a catastrophic kill of the container. If and when the test results fall between these two extremes, testing full-scale mockups or actual production items may be required.

Aircraft gun magazines containing HE projectiles present a potential vulnerability problem. The problem is complicated by the density of the packaged rounds, the reaction characteristics peculiar to each projectile configuration for each threat, and the physical location of the ammunition magazines with respect to critical aircraft structure or components.

Nonvented ammunition containers are vulnerable to the blast effects of contained ammunition reacting to small-arms bullet impact. The smaller the container, the more likely it is to be structurally damaged. This is primarily caused by the difference in internal volume. For an equivalent explosive reaction in each of two containers, it is apparent that the container with the smaller internal volume will generate the highest internal pressures.

Vented containers, in various test programs, have maintained their structural integrity to a higher degree than nonvented containers of similar construction when tested under similar conditions. Reference 89 describes firings that were conducted to investigate the vulnerability of modern-armed helicopter systems using 30 and 40 mm ammunition in large containers. Individual rounds, groups of rounds, and a variety of HE-loaded ammunition containers were used as targets. The rounds were struck on their fuzes, projectile walls, propellant cases, and primers by caliber .30 and .50 bullets. Also examined, were the effects on a helicopter containing a simulated ammunition system when 30 and 40 mm HE rounds contained in the system reacted to bullet impact. The conclusions presented in Volume II include information on the vulnerability of ammunition and of the aircraft, and techniques that can be used for vulnerability reduction.

Reference 87 presents the results of a series of test firings of various small-arms projectiles into a mockup of the AH-56A Cheyenne helicopter ammunition bay containing 30 and 40 mm ammunition magazines. The severity of structural damage for various types of ammunition reactions, potential fire hazards, magazine venting, and other resultant effects that concern overall aircraft vulnerability are discussed.

Tests to determine the vulnerability of bombs to bullet impacts are described in Reference 88. The results of the tests indicate that

small-arms-caliber armor-piercing bullets are superior to other small-arms types in their destructive effect upon 100- and 500-pound TNT-loaded general-purpose bombs.

Reference 90 describes tests that were conducted to determine the vulnerability of JATO units to single cylindrical steel fragments and bullets fired at normal or nearly normal angle of impact. Because JATO units have changed considerably since these tests, the results can give only a general idea of their vulnerability. The conclusions presented in the referenced document provide information on vulnerability of more than one type of JATO unit, related to fragment size and striking velocity.

4.11.3 DESIGN CRITERIA

4.11.3.1 Aiming/Sighting Systems: Mission success and effectiveness of an assault aircraft are greatly influenced by the accuracy of ordnance delivery. This can be highly dependent upon the usefulness of the aiming/sighting system. Consider the following means for reducing its vulnerability:

- Use methods to prevent or minimize complete failure of the system as a result of damage or failure of one of its elements caused by ballistic weapon effects. Provide redundant circuits or elements to insure full or acceptable degraded performance when subjected to hostile weapon damage.

- Locate critical system components to use natural shielding protection. Avoid those locations where secondary hazard effects, such as short-term fires, high-temperature environments, or structural deformation caused by hostile weapon effects, could degrade or destroy the component functions.

- Use a "fixed" sight capability, either automatic or selected, that is not dependent upon operation of the normal sighting/aiming system to permit delivery of the ordnance in a degraded mode.

4.11.3.2 Arming/Launching Systems: Proper arming and launching of weapons is required for effective ordnance delivery. Consider the following techniques to enhance survival and operation of arming and launching systems when exposed to nonnuclear weapon effects:

- Isolate arming and launching electrical circuits from other electrical or electronic circuits, and give them priority of protection to prevent failures or malfunctions.

- Use redundant or backup arming and/or launching systems where basic survival of the normal system is unacceptable. For example, provide a mechanically operated or emergency electrical weapon arming and/or launching system that will permit delivery of ordnance with normal electrical system inoperative due to weapon effect damage.

- Provide emergency or redundant power sources for essential operation of ordnance arming/launching system.

- Where multiple ordnance launchers or stations are used, provide separated and protected arming and/or launching circuits to avoid complete loss of weapon delivery capability due to a single hit.

4.11.3.3 Internal Gun Systems: Operation of internal gun systems is dependent upon charging, firing signals, ammunition stowage and feed systems, case and/or link disposal, and gun gas purging system performance. Consider the following techniques to enhance resistance of internal gun systems to failure or malfunction due to nonnuclear weapon effects:

- Provide gun charging and/or gas purging systems that are not dependent upon operation of a highly vulnerable electrical or fluid power system. If this dependence cannot be avoided, provide emergency backup capability for such operation. For example, provide an emergency accumulator for a hydraulically operated gun-charging or purge door operation. Automatic operation of the emergency system is preferred, along with pilot warning of primary system failure.

- Design ammunition feed systems as short as practical to minimize vulnerable area and probability of malfunction or jamming due to hostile weapon effects. Avoid rigid attachment of feed and return chutes to structure where deformation from weapon effects could cause jamming of gun operation.

- Provide case ejection chute installations that will resist failure or malfunction due to hostile weapon effects. Consider using materials that will accept minor penetration and/or blast effects and still allow case retention and/or disposal that will prevent or minimize loss of gun operation.

- Design ammunition stowage to prevent or minimize destructive buildup of pressures within the aircraft structure and ammunition stowage areas. Where impact and ignition of stowed ammunition can occur, provide vented ammunition containers and compartments

to avoid explosive damage from rapid burning of ammunition propellant or high-explosive warheads. See Figure 160 for an example of a vented ammunition storage container configured to allow rapid escape of burning propellant gas and prevent a hazardous explosion within the aircraft structure.[32]

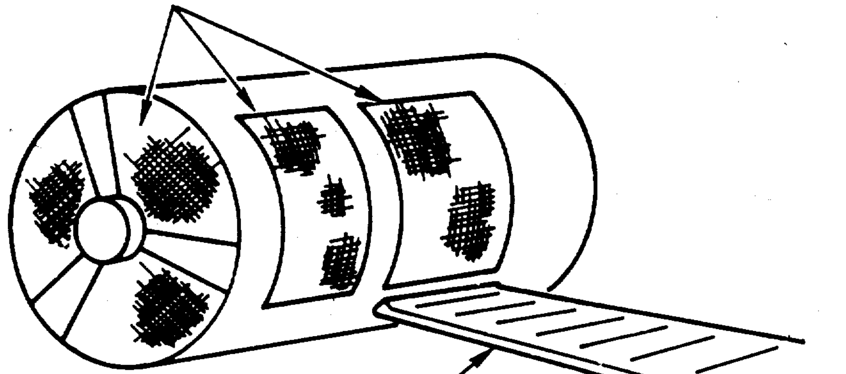

Figure 160. Vented Ammunition Storage.

4.11.3.4 Carriage Systems: Weapons may be carried either internally or externally, depending upon the specific weapon and aircraft. Each of these carriage mechanisms may carry arming, release, force ejection, jettison, and sequencing systems that weapon effects may damage and cause to become inoperative.

4.11.3.4.1 Internal Carriage: Bombs, rockets, missiles, etc., may be carried internally in weapon bays, for aerodynamic concealment or special environmental reasons. Consider the following survivability design enhancement techniques to achieve required level of mission completion when aircraft is exposed to hostile nonnuclear weapon effects:

- Design weapon bay door hinges and actuating mechanisms to prevent or minimize jamming from blast or weapon penetration effects.

- Provide redundant or emergency power sources for weapon bay door and articulated weapon positioning devices such as missile or rocket launchers. Hydraulic, pneumatic, and electrical systems are the primary types that should be compared to determine which one, or combination, will provide the most survivability for the

specific application. The emergency backup system may be hydraulic accumulators, pneumatic pressure bottles, batteries, cartridges, or other stored energy devices.

- For installations where weapon bay doors may be jammed or become inoperative from weapon effects, provide a means to jettison doors. Frangible or explosive hinge pins or explosive primer cords are examples of such means.

4.11.3.4.2 External Carriage: Provisions for the external carriage of weapons are generally flush-mounted to, or semisubmerged in, structure or mounted on pylons. Consider the following enhancement techniques to achieve required level of mission accomplishment:

- Concentrate operating linkages and equipment to minimize their vulnerable area and possibility of jamming or malfunctioning from weapon effects.

- Provide single-motion jettison capability for external weapons that are capable of producing a hazardous condition such as ignition of incendiary bomblets and flares.

- Mask weapon arming and actuation of electrical circuitry in external pylons to present the least vulnerable aspect or area to weapon effects. Where this cannot be avoided, use redundant circuits.

4.11.3.5 General: Mission-essential elements, components, and hardware should be located to make use of natural masking protection.

Locate ballistic-impact and incendiary-sensitive ammunition and/or other ordnance so as to minimize personnel injury/fatality and damage to essential subsystems from explosion or burning initiated by hostile weapon effects. Consider the relative merits of external and internal carriage.

Provide adequate venting of internal ammunition containers to avoid destructive buildup of gases generated by burning explosives.

Consider venting aircraft fuselage in area of ammunition storage.

Consider the use of heat barriers and/or fire suppression systems for sensitive ordnance compartments to limit damage.

4.12 ELECTRICAL POWER/AVIONICS SYSTEMS

4.12.1 INTRODUCTION

The techniques and practices of electrical and electronic designs include several elements that also enhance the equipment capability to survive ballistic threats from small-arms projectiles. For example, the redundancies built in for reliability purposes can be installed so that survivability is also enhanced. The power-limiting functions built into all electrical distribution systems protect the system if a projectile causes a short circuit, and the design objective of minimum volume also minimizes the equipment presented area. The following paragraphs are intended to provide survivability enhancement methods that can be integrated with general design practice.[32]

4.12.2 BALLISTIC DAMAGE EFFECTS

Electrical power and avionics systems are particularly sensitive to the primary and secondary damage mechanisms associated with small-arms weapon effects. Primary effects are those that are the result of projectile penetration and impact. These effects can cause severance of electrical wires, penetration and tearing of equipment, and shorting of electrical circuits. Secondary weapon effects are those hazardous effects created by projectile impacts that, in turn, can adversely affect electrical and electronic elements. These include fires, explosions, high-temperature conditions, and liberation of hazardous materials. Failure modes of electrical and electronic elements are disruption and shorting of circuits, and malfunctioning of equipment.

4.12.3 SYSTEM DESIGN CONSIDERATIONS

Aircraft electrical power and avionic systems use similar types of equipment and transmission systems to perform their required functions. Survivability enhancement techniques are, therefore, applicable to both. The following are basic considerations that can be incorporated into specific designs to improve survivability.

4.12.3.1 Circuit Design: Electrical power supply systems normally contain redundant circuitry for reliability and safety requirements that in themselves provide a degree of inherent survivability enhancement. Minimizing the vulnerability of such redundant systems dictates the need for adequate physical separation of the circuits, with natural "masking" by structures or other equipment that minimizes the probability of simultaneous failure from single or multiple projectile hits from

predominate threat directions. Electrical and avionic equipment should be activated through control of the electrical signal or power, rather than by a grounding-type circuit. This will minimize the quantity of "live" circuits in the aircraft, that can become potential ignition sources for flammable or explosive conditions generated by ballistic impacts. For equipment whose accidental activation, by battle damage, would endanger the aircrew's or aircraft's flight performance, consideration should be given to providing grounding of both input and output leads of such units. Figure 161 illustrates both types of circuits.

A specification of redundancy in an avionics function stems from the two requirements of reliability and vulnerability enhancement. Accordingly, the two requirements should be applied through a combined analysis. Vulnerability enhancement requires spatial separation of redundant functions and, in this way, extends beyond a parallel reliability requirement. In some cases, redundancy may be considered for vulnerability enhancement of a function, although it is not required to attain reliability goals. However, there will usually be a reliability benefit to be considered.

The requirement for fail-safe electronics components with respect to vulnerability differs from that with respect to malfunction. A ballistic input generally deranges circuitry and wiring so that circuit analysis techniques no longer apply. For example, consider an impact that shorts incoming power connections of an amplifier. A fail-safe mechanism built into the amplifier circuitry does not apply, and any circuit protection must be on the generator side of the connection. A similar problem exists with respect to a grounding connection. If a ground is opened as a result of projectile impact, then potential differences may lead to extension of the damage:

a. To the equipment concerned

b. To other equipment electrically connected

c. To flammable materials that may be exposed to arcing

System emergency power is one of the redundancies commonly used to support aircraft system requirements. Usually, an aircraft electrical power system will incorporate one or more standby or emergency modes for reasons of reliability and survivability. As is the case with any redundancy, the emergency power system components must be separated from the normal system components to attain the survivability enhancements. In practice, there are usually several ways in which the redundant power sources can be connected to the electrical loads. For example, Figure 162 shows a single

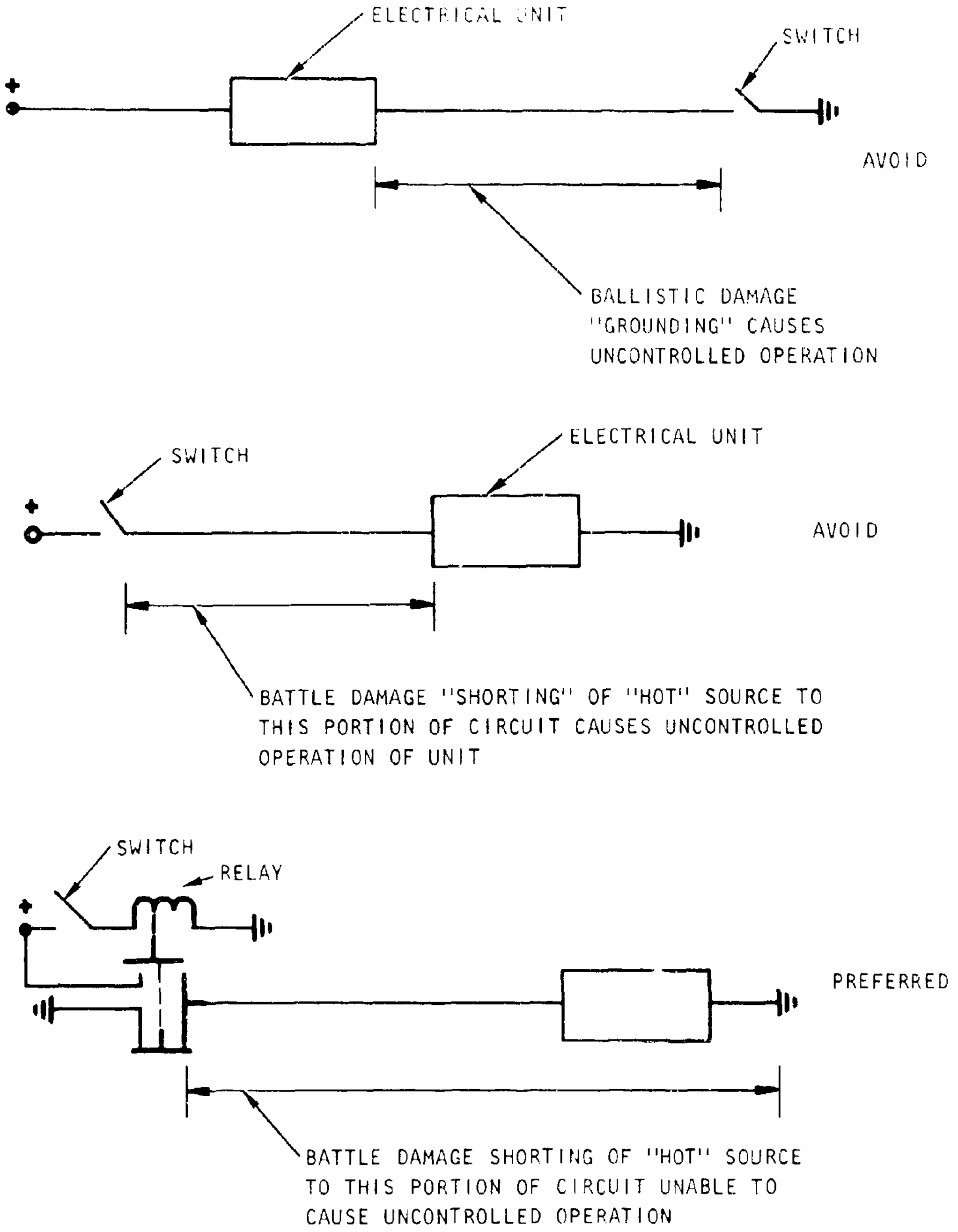

Figure 161. Electrical Circuit Switching Concepts.

power bus served by two generators. Figure 163 shows two separate busses and a "MAIN-OFF-EMERGENCY" switch for each component. This configuration provides an added separation. The power switches can be placed at the component locations; single redundancy is not involved. Another option available to the configuration is limitation of the emergency generator load by connecting only the more critical equipment loads to that bus.

4.12.4 DETAIL DESIGN

System electromagnetic interference (EMI) parameters and other factors usually require electronic enclosures that are fairly substantial. The shielding provided by such enclosures is not effective against projectiles, but it does provide some protection against other ballistic effects such as blast, fire, and spallation. For system purposes, it is often necessary to locate electronics boxes in areas where hazards from secondary ballistic effects are high. Areas situated so that threats can cause accumulation of fuel or high-temperature engine gases are examples of high-hazard areas. If it is necessary to locate all electronic boxes in a high-hazard area, particular attention should be directed toward enclosure design to enhance resistance to the hazardous effect.

This enhancement usually involves insulation of the box from the heat and flame. An important parameter in determining such a requirement is the length of time the hazard is expected to exist. If a fire extinguishing function is specified, a fuel fire should be expected to be of short duration. Another time-limiting factor is that a fuel fire of long duration may be expected to destroy the aircraft.

Electrical connecters and wiring situated in potential high-temperature areas should be designed with temperature-tolerant features such as heat-resistant potting materials and wiring coverings.

Terminal strips concentrate interconnections into a small space. Such a concentration may permit a single ballistic impact to inflict widespread damage to the functions concerned. Alternative constructions should be considered for critical circuits to minimize and limit damage.

4.12.5 INSTALLATION

If an electrical/electronic (e/e) system is critical to the mission and no redundancy exists, then the component installation must consider suitable masking from the ballistic threats or armor provisions.

The location of components is critical from a secondary hazard standpoint, if it provides an ignition source when damaged. The installation of some

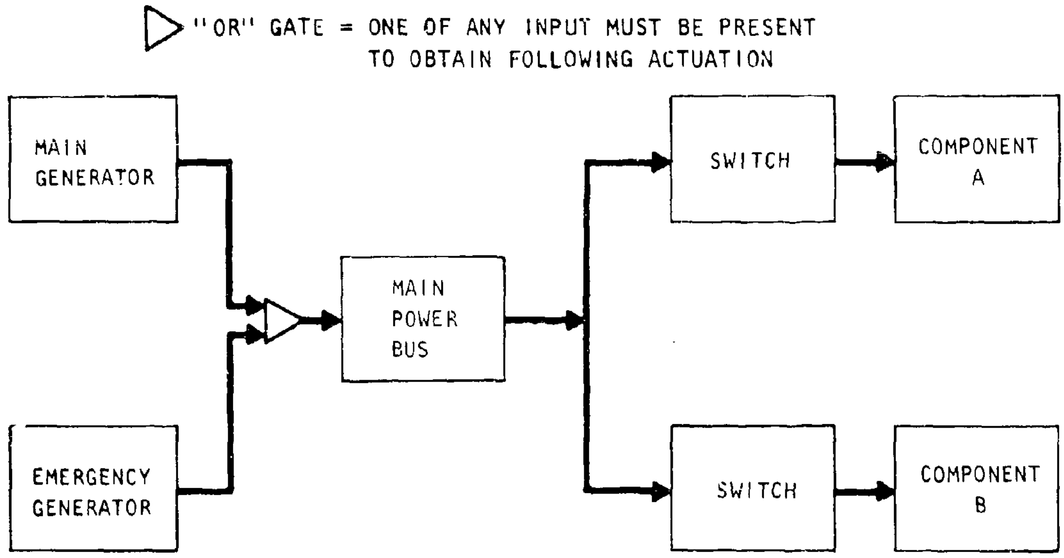

Figure 162. Single Power Bus System.

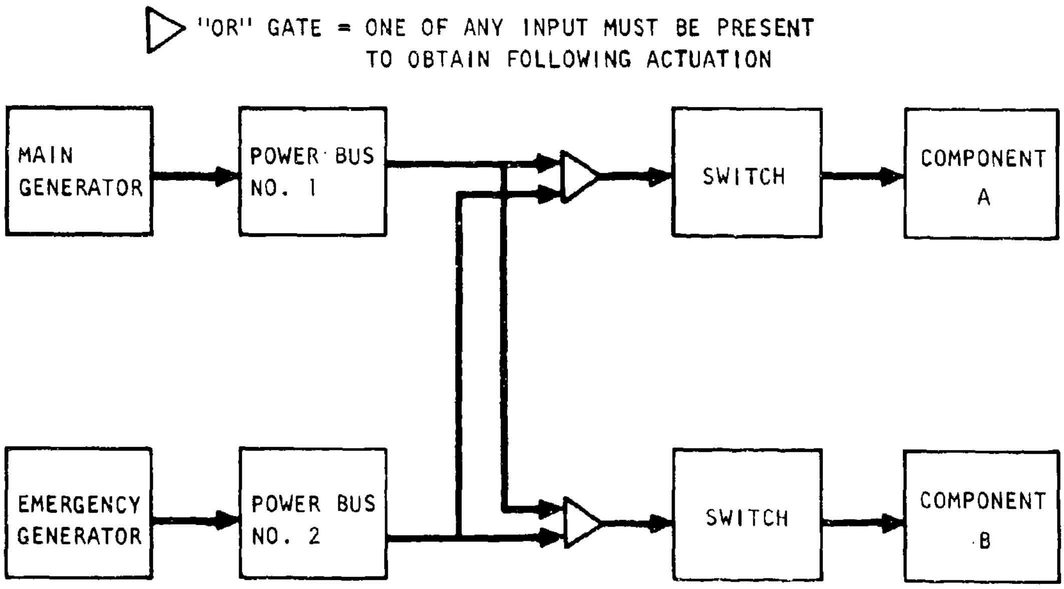

Figure 163. Separate Power Bus System.

electrical equipment includes a grounding connection to the structure. If this connection is broken, the potential difference can be a highly efficient ignition source. Ignition can occur from voltages of as little as 0.5 volt, from a point contact between the two potential levels.

Capacitance-type fuel quantity measurement systems commonly use a potential difference of up to 75 volts. Any possibility that debris or other material from ballistic damage could cause a short circuit in such a system should be carefully scrutinized.

Electrical cabling for essential circuits should be routed to obtain the most effective masking by heavy structure and components from the direction of most probable enemy gunfire. Where redundant circuits are used, they should be physically separated. The use of single connecters in potentially vulnerable areas should be avoided. Critical circuits' wiring should be isolated from that of noncritical circuits to minimize battle damage cross-shorting. Insulated cable raceways should also be used for critical electrial power or avionic systems to minimize probabilities of damaged wire shorting to structure.

Batteries should be designed or procured with ballistic impact tolerance and should provide a degree of power, even when damaged. Battery bays should be sealed to prevent migration of corrosive battery acids to nearby sensitive equipment or components. Provisions should be made to drain or vent corrosive fluids and/or vapors overboard to locations that are not sensitive to corrosive fluids.

4.13 LANDING SYSTEMS

4.13.1 INTRODUCTION

Landing systems on rotary- and light fixed-wing aircraft have not shown any significant vulnerability to small-arms ballistic threats, since they are, for the most part, the fixed, nonretracting type. Landing systems are designed to accept large dynamic loads for safety and crashworthiness factors, which provide them with an inherent tolerance to ballistic impacts. The Crash Survival Design Guide provides adequate generalized crashworthiness information. Vulnerability, however, cannot be overlooked for future, more sophisticated and higher performance Army aircraft.

Landing systems are divided into two major classifications: fixed gear and retractable gear. A simple fixed-gear landing system usually consists of two strut-mounted, shock-dampened skids aligned longitudinally along the aircraft fuselage. The right and left skids are usually connected to

the aircraft fuselage through removable struts and side braces that pivot as a unit when the shock damper assemblies are extended or retracted through their actuation stroke. Another type of fixed landing gear system consists of a three to four strut-mounted, shock-dampened wheel assemblies using either a conventional (tailwheel), tricycle, or quadricycle gear configuration. The wheel assemblies are attached to shock struts (or oleo units) which are connected to the aircraft fuselage structure. A retractable landing gear system usually consists of strut-mounted, shock-dampened wheel assemblies using either a conventional or tricycle gear configuration with the capability to retract the wheel and strut assemblies into the aircraft fuselage or sponson-type structures to improve aerodynamic smoothness.

4.13.2 BALLISTIC DAMAGE EFFECTS CONSIDERATIONS

Coinsideration must be given to the ballistic damage effects to which the landing system will be exposed over the full range of the aircraft mission to insure that no system weakness is overlooked. Damage effects may be caused by penetration of ballistic projectiles (small arms) and secondary spallation fragments' piercing, shattering, or severing critical elements or components and the ignition or incendiary effect of flammable hydraulic fluids. The landing system must be designed to accept some ballistic damage without losing its capability to perform its full function or jeopardizing safety. A systematic method should be followed to identify vulnerable elements, their failure modes, and their effects upon mission-essential or recovery functions. Figure 164 shows a simplified functional flow diagram for a retractable landing system. This representation of the system can be used to assess the damage mode and effects from ballistic threats. By accomplishing this analysis, all vulnerable portions of the system can be identified for application of survivability enhancement techniques. Redundancies in the system are shown by use of "OR" gates, while "AND" gates are used where more than one element is needed to perform a given action.

4.13.3 BASIC DESIGN

4.13.3.1 Fixed Gear: The following are those survivability enhancement techniques to be used as a guide in the initial design or modification of fixed landing gear systems:

a. Design landing system and components with multiload path capability and damage tolerance to avoid landing hazards from single-element damage or failure.

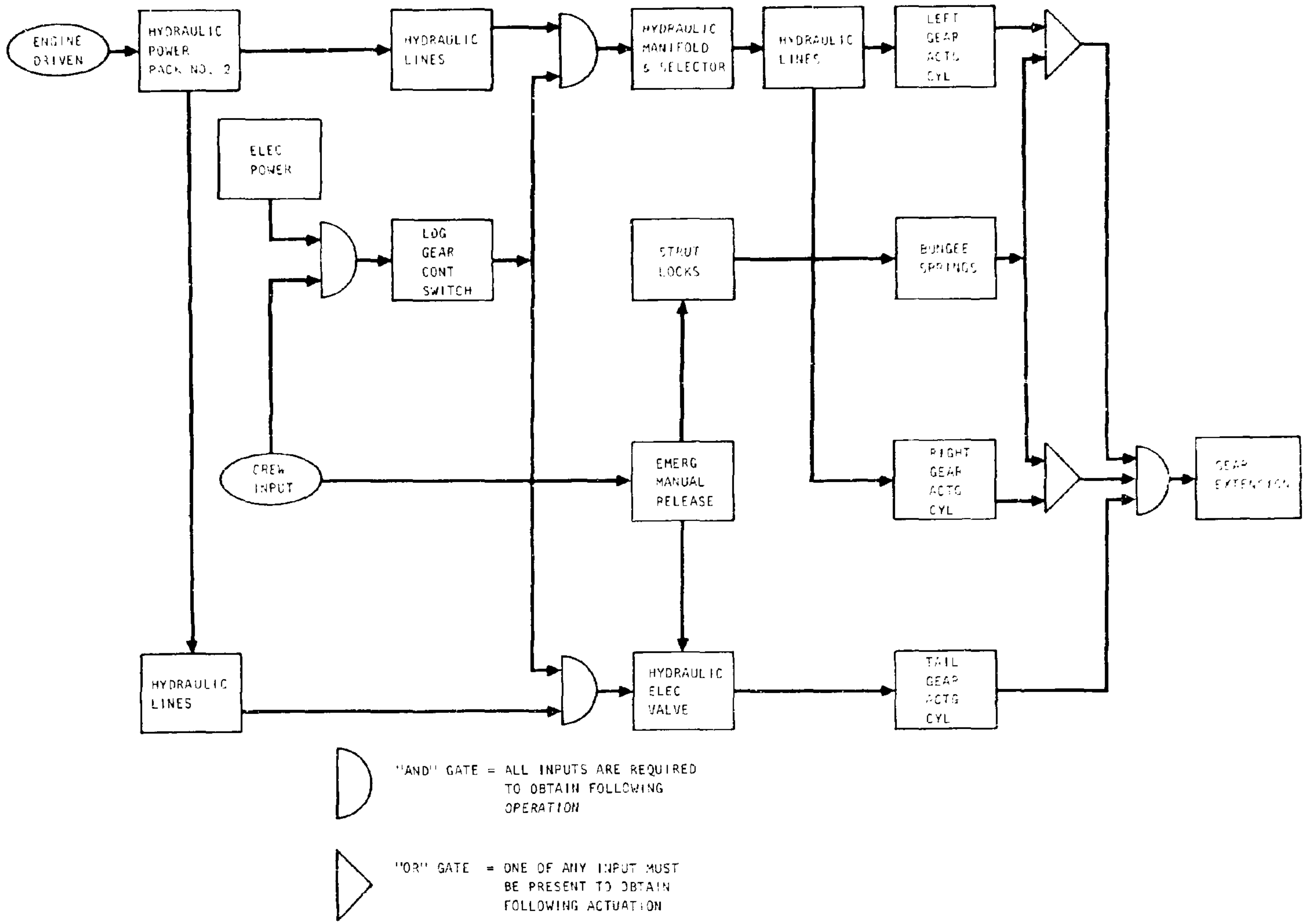

Figure 164. Representative Retractable Landing Gear System (Functional Flow).

b. Provide for use of large-diameter, thin-wall tube construction for critical landing system linkages, struts, or supports.

c. Avoid landing gear to fuselage attachment designs using brittle materials such as castings, which could otherwise fail when struck by a projectile. Provide for use of large-area ductile material which will accept projectile or fragment penetration with minimum probability of element failure.

d. Avoid major attachment points using only one primary securing element that would be susceptible to ballistic damage failure. Provide for multiple securing elements at critical attachment points.

e. Design for lowest practical shock strut or damper internal pressures to minimize disintegration from ballistic impacts.

f. Design for lowest practical tire pressures to minimize tire and wheel destructive disintegration from ballistic impacts.

4.13.3.2 Retractable Gear: The following are those survivability enhancement techniques to be used as a guide in the initial design or modification of retractable landing gear systems:[32]

a. Provide for manual free-fall release and extention of retractable landing systems.

b. Provide for adequate separation of electrical power sources and hydraulic/pneumatic lines to avoid simultaneous failures from ballistic impacts or spallation.

c. Route manual release control cable as close as practical to heavy primary structure to provide masking against ballistic threats.

d. Avoid landing gear attachment designs using brittle materials such as castings for basic support structure.

e. Compare relative benefits and penalties for the use of electrical versus hydraulic/pneumatic power sources in basic design concept. Electrical power sources are generally less vulnerable than hydraulic or pneumatic sources, and are more easily adaptable for redundancy. Electrical sources, however, usually require greater space and are heavier than comparable fluid sources. Survivability design techniques for fluid power sources are provided in Paragraph 4.10.

f. Design for easy replacement and/or repairability of landing struts that can easily be damaged from ballistic effects or forced/crash landing.

4.13.4 DETAIL DESIGN

4.13.4.1 Components: These include shock struts, wheels, brakes, actuating cylinders, valves, accumulators, and drag braces. Consider using the following detail design criteria to minimize failure or other system degradation due to ballistic effect damage:

a. Provide for construction of components from materials that resist failure from cracking or shattering when struck by projectile threats or secondary spallation.

b. Consider the lowest possible tire pressure for wheel assemblies to minimize destructive disintegration from ballistic impacts. Consider the use of foam-filled tire assemblies in lieu of the pneumatic type.

c. For detail design criteria for hydraulic or pneumatic components, refer to Section 4.10.

d. For detail design criteria for control rods and control linkages, refer to Section 4.9.

4.13.4.2 Attachments: The following design techniques should be considered to incorporate effective survival enhancement features in the landing system attachment design development:

a. Avoid landing system attachment designs using brittle materials such as castings which could shatter/crack and fail when struck by projectiles or fragmentation. Consider structural attachments using ballistic-resistant or high-fracture-toughness materials.

b. Avoid landing system major attachment points using one primary securing element. Provide for multiple securing elements at critical attachment points.

c. Design attachments and supports for essential subsystem mechanisms to resist failure or jamming from ballistic damage (i.e., gear retraction and extension system).

CHAPTER 5

TRADE-OFF STUDY FACTORS

5.1 INTRODUCTION

After the practical techniques of survival enhancement have been identified, it remains to determine which approach offers the best solution in overcoming the conventional weapon threats.

This section addresses the objectives of a trade-off study program and the factors involved in obtaining an effective design configuration. The interrelationship of trade-off studies and the normal design process is an important factor.

Each principal protection concept exhibits certain inherent advantages and disadvantages which must be weighed in the selection of the approach best suited to a particular aircraft design concept and its intended operational use.

The end objective of a trade-off study is to identify the influence that candidate survival enhancement techniques have on all design factors and to provide design management the necessary data to support decisions related to proposed changed and/or improvements that may be implemented. Trade-off factors and design sensitivity factors must be identified, and the impact on the aircraft concept and mission requirements must be analyzed.

Since there is no standard methodology established for survivability/vulnerability trade-off studies of Army aircraft, this section presents an approach that contains the basic elements that should be considered for such a program.[91]

The basic trade-off factors for survivability enhancement features are related to the effect each has on the overall system effectiveness and lifetime cycle costs, including combat and noncombat operations. They include the following areas:

- Probability of survival (P_S)
- Vulnerability

- Safety
- Maintenance
- Reliability
- Logistics
- Performance
- Cost
- Operational effectiveness

5.2 TRADE-OFF STUDIES TASK

5.2.1 IDENTIFICATION OF CRITICAL SUBSYSTEMS AND COMPONENTS

A systematic study is needed to identify, quantify, and relate trade-off factors to a specific design concept. Trade-off studies tasks and the interrelationship that exists during the design process are displayed in Figure 165.

Starting with either new or existing aircraft design, mission requirements, and threat encounters, all mission-critical systems and components are identified. This identification must consider which mission functions are necessary to fulfill flight or mission requirements. Critical components and systems are identified by "kill categories," the degree of criticality depending upon the operational requirements of mission functions, and the spectrum of threats to be addressed. The process for this task is contained in Paragraph 1.3.

5.2.2 ASSESS VULNERABILITY AND SURVIVABILITY

Once the critical subsystems and components have been identified, their vulnerability to the range of hostile threats is determined. This vulnerability data, in turn, is used to determine the probability of survival for each of the expected encounter conditions. This information is used as one of the inputs to the system cost-effectiveness analysis. The parameters associated with survivability/vulnerability (S/V) factors include:

- Encounter survival
- Mission survival

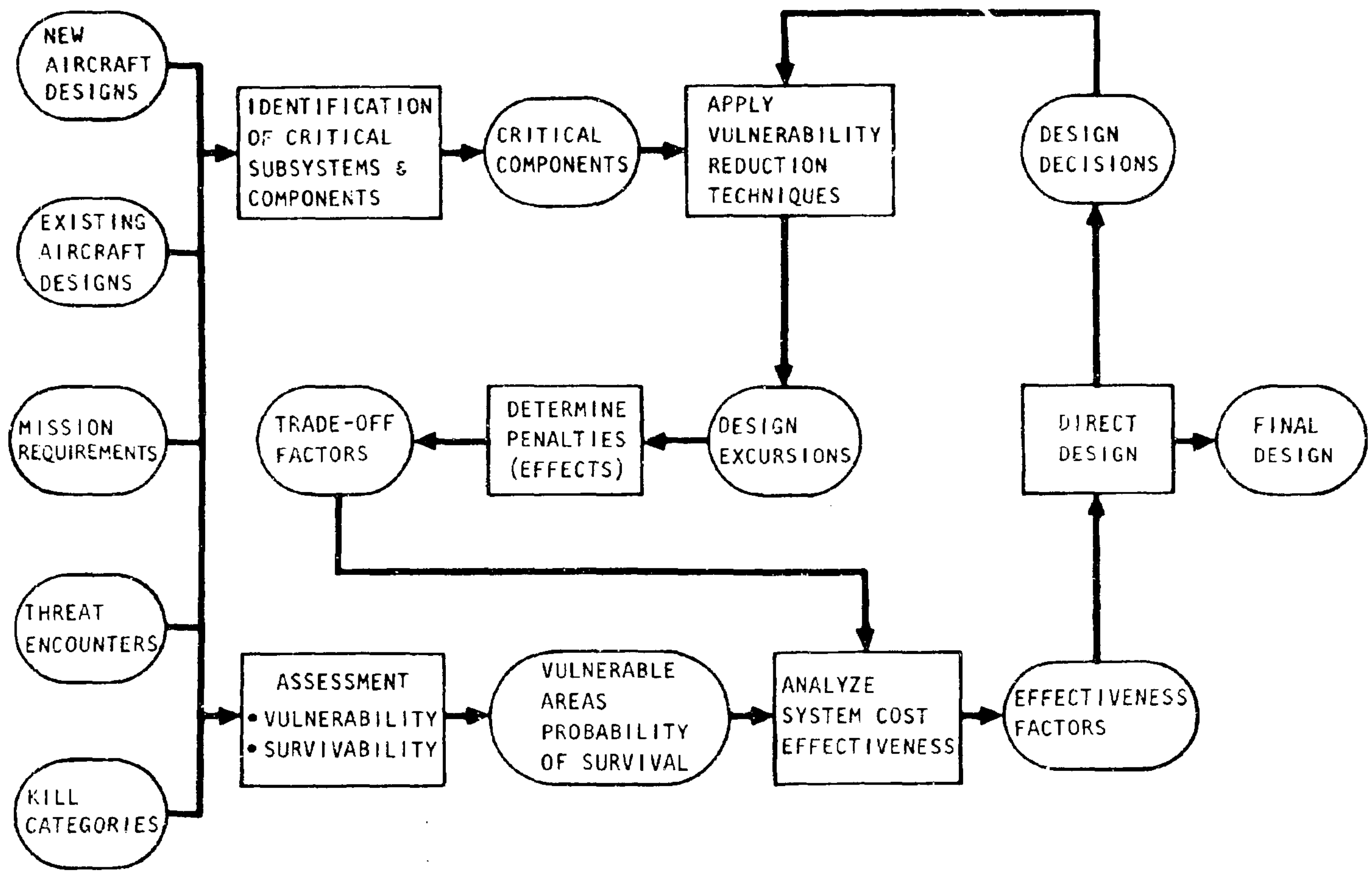

Figure 165. Survivability/Vulnerability *Trade-Off* Studies Program.

- Total force survival
- Aircraft survival to recovery
- Missions aborted due to battle damage
- Vulnerable areas per threat

Survivability assessment methods consider the aircraft mission flight profiles, speed, altitudes, penetration distances, attack tactics, numbers and types of defense elements encountered, exposure times, number of rounds fired, firing errors, and kill probabilities in computing mission or sortie probability of survival or other measures of effectiveness. In the broadest sense, these techniques use measures that reflect the probability that an aircraft will survive to accomplish its mission because of the action of enemy defenses. These measures involve both active and passive defense capabilities of the aircraft, as well as the abilities of the enemy defense systems to find, hit, and destroy the aircraft. At present, no standard general evaluation method exists that will make such an evaluation possible for the wide class of situations that are encountered. Vulnerability assessment models, for example, are generally restricted to situations where it is assumed that the aircraft has suffered a single hit or multiple hits in specific subsystems, with exposure to a specific type, of hostile defense weapon. The results (vulnerable areas) are then integrated into more general survivability models according to the particular situations involved. The general models evaluate survivability enhancement techniques in terms of increased survival payoffs and/or improved system effectiveness. Examples of aircraft-mission combinations are summarized in Table XXVI.

An integral part of the survivability assessment task is the technique of calculating vulnerable areas. (Refer to Paragraph 1.3.1.)

The vulnerable areas of an aircraft are sensitive to size, type, striking velocities, and aspect angles of projectiles, and the kill category (i.e., allowable response) being considered.

5.2.3 ANALYZE SYSTEM/COST EFFECTIVENESS

Factors that should be considered in the system/cost-effectiveness analysis are defined in the following paragraphs.

5.2.3.1 Safety: Probable changes in system safety rates must be evaluated for candidate survivability enhancement techniques. In most cases, they

TABLE XXVI. AIRCRAFT-MISSION COMBINATIONS	
Aircraft Type	**Mission**
Helicopter	Weapon delivery, reconnaissance
Helicopter	Transport, rescue
Helicopter	Aerial delivery
Utility and Cargo (Conventional and V/STOL)	Transport, rescue
Utility and Cargo (Conventional and V/STOL)	Aerial delivery

would be expected to be improvements for safety. For example, a lubrication bypass system that permits continued flight after weapon effects damage to an oil cooler also provides a greater probability of safe recovery of the aircraft and aircrew because of a material failure or maintenance error that also results in lubrication oil leakage from the oil cooler and its associate lines, hoses, and components.

Aircraft crashworthiness is defined as the ability of the aircraft structure to maintain living space for occupants throughout a crash, as well as the ability of the particular personnel seating and restraining system to adequately support the individual against the accelerations produced during a potentially survivable aircraft crash. This parameter also includes the requirement for insuring that the integrity of the aircrew station area is not violated through the failure of bracketry or attachments which are used in installing passive defense provisions. An obvious degradation to crashworthiness will involve the effects of armor weight added to the seat or system, and also the backup structure which ultimately carries the loads transferred from the seat-man combination during a crash situation.

These factors should be evaluated to determine their contribution to changes in:

- Accidents per flying time
- Aircrew survival per accident

5.2.3.2 Maintenance: Addition of survivability design features as a modification to an existing aircraft generally results in an increase of maintenance man-hours, (scheduled and unscheduled) for the total system. For new designs, the penalities can be minimized and, in some cases, may result in benefits. Each design feature must be judged on its own merits, such as the man-hours required to remove and replace parasitic armor in order to gain access to a malfunctioning or time-inspection-limited piece of equipment.

Concentration and integration of a number of components in a subsystem, to minimize its vulnerability to weapon effects, may also require less maintenance effort and time to troubleshoot and repair.

These factors are evaluated for changes in:

- Maintenance man-hours per flight hour (MMH/FH)
- Downtime per flight hour
- Mean task times (accessibility)

5.2.3.3 Reliability: System reliability values can be affected by survivability enhancement features. The addition of redundant subsystem circuits may impose higher reliability requirements upon individual components within each of the redundant systems in order to attain the overall system reliability allocations.

These factors are evaluated for changes in:

- Component reliability
- Component redundancies
- Mission success reliability

5.2.3.4 Logistics: The operation of military aircraft requires logistic support in order to perform their designated missions. The major items that can be affected by survivability enhancement features include fuel consumed, spares required, and pay load (munitions) expended to achieve a given level of combat effectiveness. The addition of weight to a design, for survivability improvements, requires more fuel to be used to achieve a given level of performance. Increase in system complexity will affect

the number of aircraft for specific missions over a given time period. These factors are evaluated to determine the changes affected in terms of dollar costs.

5.2.3.5 Performance: Aircraft performance penalties are generally expressed in terms of mission range (or radius) or loss or reduction in payload. For major subsystem additions in the case of advanced aircraft designs, the penalities may be expressed in terms of aircraft growth, with performance factors remaining constant. Modifications to the fuel subsystem (foam in tanks, self-sealing tanks, etc.), for example, will result in a dry weight penalty and a corresponding reduction in fuel weight due to displacement. The combined effect of an increase in dry weight and a decrease in internal fuel weight can result in either decreased mission range capability or a reduced payload. Major changes may also affect limitations on aircraft speed and maneuverability. Smaller changes and weight additions will generally have a negligible effect on aircraft performance. Techniques which require displacement of external store stations can also significantly affect aircraft performance, depending on the particular aircraft and store configuration. Figure 166 shows a representative plot of performance trade-off results for a basic mission flight profile and payload.

Aircrew performance factors refer to the effects which the principal protection concepts have on the ability of the aircraft aircrew to perform their assigned tasks such as flying the aircraft, navigating, accurately delivering weapon/payloads, observing the terrain flown over, etc. The parameter also includes the effect on personnel mobility during emergency egress.

Performance factors are measured for changes to those accountability items that influence cost or effectiveness:

- Mission range
- Payload capability
- Turnaround time
- Radar cross-section signature
- Infrared (IR) signature

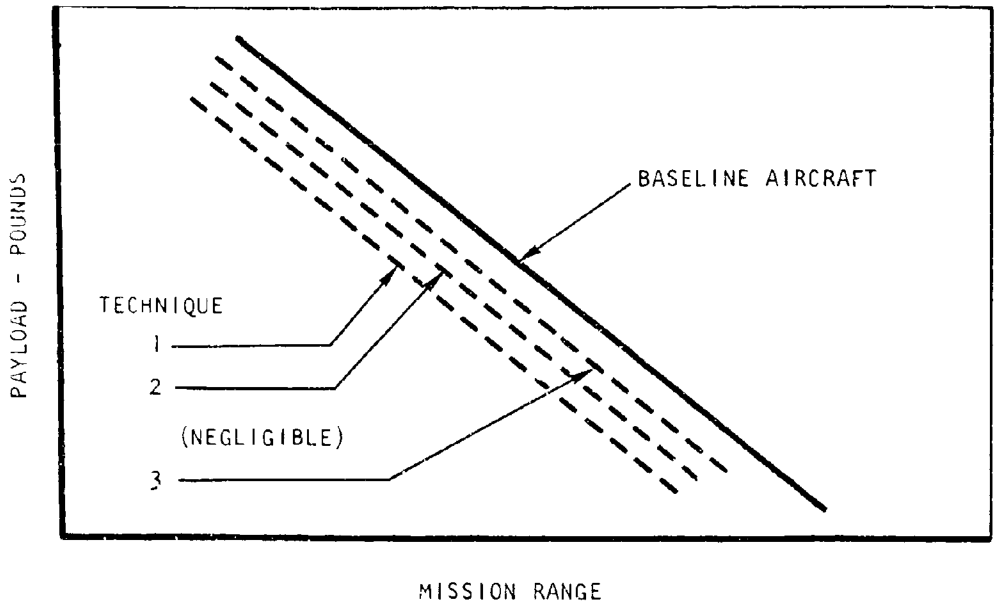

Figure 166. Effect of Survivability Enhancement Techniques on Aircraft Performance.

5.2.3.6 Operational Effectiveness: The capability of an aircraft to perform its designated missions is a measure of its operational effectiveness. The parameters involved in this area are:

- Combat missions accomplished
- Number of targets killed
- Number of aircraft available for flight
- Number of training missions accomplished
- Utilization rate (number of hours flown per month)

5.2.3.7 Costs: The costs of an aircraft system is the one factor to which all trade-off study values must be ultimately related. It provides a basis upon which design management can decide what combinations of survivability enhancement features will be the most effective for a specific design configuration and hostile threat spectrum.

Cost factors that may be influenced by survivability/vulnerability features are:

- Development costs (RDT&E)
  - Aircraft design
  - Tests
  - Research
- Acquisition costs
  - Production aircraft
  - Spares
- Life cycle costs
  - Peacetime operations/logistics
  - Wartime operations/logistics
  - Peacetime attrition
  - Wartime attrition

5.2.4 EFFECTIVENESS FACTORS

From the system/cost-effectiveness analyses, the relative value of S/V factors are compared to provide design management with data needed for design direction. For each candidate S/V feature, it is generally not practical or economical to perform a total system/cost-effectiveness analysis to determine its impact upon the overall program. It is convenient to develop and use sensitivity factors, instead, that can give reasonable comparisons for several candidate S/V features that can be quickly determined. For small increments of change from the basic design, sensitivity factor changes tend to be linear. Figure 167 shows a hypothetical curve for the effect of probability of survivability (P_S) has upon the total system cost. The excursions from the baseline system costs define the limits for the cost sensitivity factor rate of change

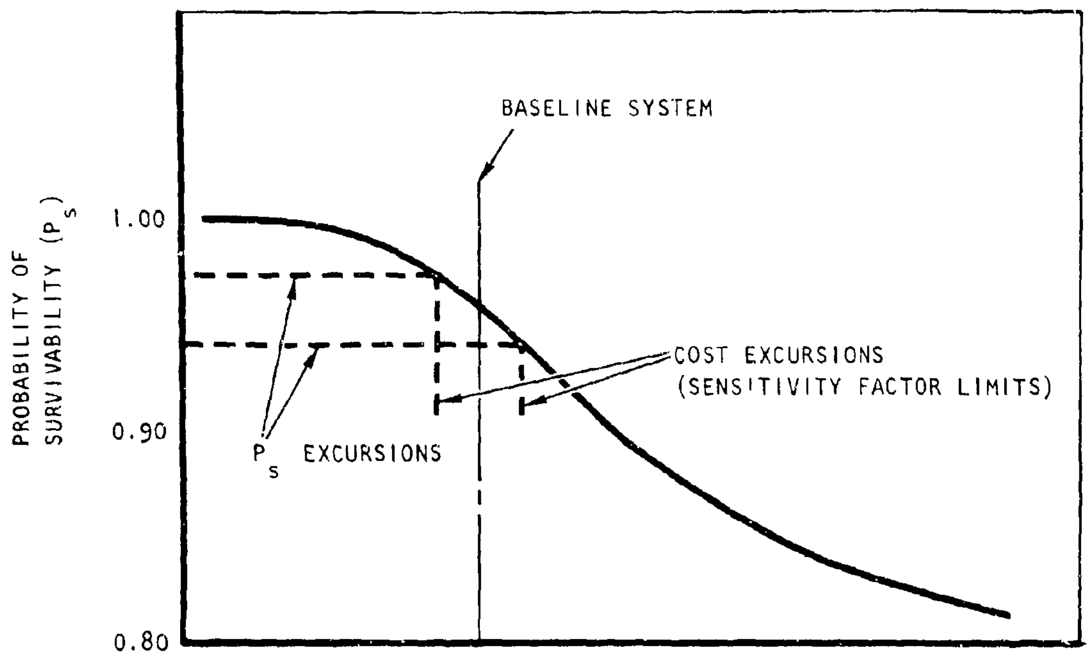

Figure 167. Relationship of Probability of Survivability to Total System Cost.

for the corresponding change in P_S. In a similar manner, other changes induced by the incorporation of an S/V feature into a design may be determined.

Changes in trade-off factors resulting from different survival enhancement techniques can be organized in a table format (refer to Table XXVII). Such a table displays details in selected important trade-off factors for various candidate designs that use survival enhancement techniques.

For different types of aircraft and missions, weighting factors may be used to provide proper comparison of design change parameters. Table XXVIII shows one method of tabulating such weighting factors.

The information in Tables XXVII and XXVIII is used in the system cost - effectiveness study where sensitivity factors are generated and recommendations are formulated to provide design management the necessary data to support selection of a final design that incorporates the most effective survival enhancement techniques.

TABLE XXVII. CANDIDATE SURVIVAL ENHANCEMENT FEATURES TRADE-OFF STUDY COMPARISON SUMMARY

Trade Factors	Delta Changes to Baseline Configuration for Candidate Survival Enhancement Features					
	Candidate A		Candidate B		Candidate C	
	Trade Factor Value	Total System Cost Effect	Trade Factor Value	Total System Cost Effect	Trade Factor Value	Total System Cost Effect
Vulnerability (A_V)						
Survivability (P_S)						
Weight (lb)						
Cost ($)						
Maintenance (MMH/FH)						
System Safety						
Total System Cost (Delta)						

TABLE XXVIII. TRADE-OFF WEIGHTING FACTORS FOR DIFFERENT AIRCRAFT TYPES (EXAMPLE ONLY)

Parameter	Relative Weighted Rating		
	Helicopter	Utility and Cargo	Observation
Effect on Aircrew Performance	5	5	5
Crashworthiness	4	5	5
Convertibility	4	4	3
Relative Weight Increase	4	3	5
Aircraft Performance	3	2	2
Maintainability	2	2	3
Reliability	3	3	3

5.2.5 DESIGN DECISION

The survival enhancement techniques to be incorporated into the final design must of necessity be selected by design management. These decisions are based on trade-off factor considerations and relative importance which are reflected into total system cost and effectiveness values.

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GLOSSARY

Aerodynamic mold line surface - The common surface of the aircraft exterior and the air medium the aircraft traverses.

Angle of obliquity - The angle from the normal to a target surface and the line-of-flight of an impacting penetrator.

Areal density - The weight per unit area of a complete armor system to defeat a given threat expressed in pounds per square foot of surface area.

Armor material - Material having those properties required to provide a measure of protection against ballistic attack.

Armor system - A combination of one or more elements made of basic armor material to form an effective ballistic protection device.

Army ballistic limit - Ballistic protection criteria formerly used by the U. S. Army.

Ballistic limit - The striking velocity of a kinetic energy fragment or projectile below which partial (rather than complete) penetrations of the target will predominate.

Ballistic load - The transient impact load on a structure as a result of the ballistic impact.

Ballistic protection - An active or passive defense of a system that protects it from terminal damage effects.

Ballistic threat - The ballistic projectile fired from a hostile gun system.

Complete penetration - Piercing of the witness plate behind the target by an impacting projectile or target material fragments.

Component (system) response - The response of a component (system) to a given weapon effect.

Composite armor - An armor system consisting of two or more elements joined together to provide ballistic protection

Composite contour envelope - An envelope that represents the maximum and minimum contours of all subjects used in a given study.

Composite contour method - A method for relating the three-dimensional characteristics of the body to the appropriate armor contour. The method uses a flexible drafting curve that is quickly and easily configured to a man's shape and then traced on paper.

Conventional weapon - Any weapon whose damage mechanisms do not include nuclear effects.

Convertibility - The capability to convert from one ballistic protection level to another (such as from 7.62 mm projectile level armor protection to 12.7 mm projectile level).

Cookoff - The detonation of ammunition or other explosive components because of fire or high thermal conditions.

Damage mode - A particular form, variety, state, condition, and/or configuration of threat-connected damage of a portion or an element of an aircraft.

Distortion grid method - A method of measuring the changes in the location of grid points marked on a man's body as he goes through a complete series of movements representative of his military duties.

DHSA - Dual-hardness steel armor.

DPSA - Dual-property steel armor.

Experimental armor - Any armor configuration for which military specifications have not been established.

Fair impact - Impact criteria used in the determination of ballistic limits.

Flight essentials - The aircraft functions that are essential for maintenance of flight.

Fragment simulating projectile - A specially shaped projectile, for ballistic testing, intended to simulate the effects of typical fragments.

Homogeneous armor - Armor made from a single material which is consistent throughout in physical properties and degree of hardness.

Horizontal contour envelope - A method for graphically depicting the contours of a man's body and of body armor for the horizontal profiles.

Hostile weapon - A weapon which is available to and used by hostile forces.

Hydraulic ram effects - A liquid pressure pulse, usually of short duration, caused by absorption of kinetic energy from a penetrating body by viscous action of the fluid.

Integral armor - Armor material used as part of airframe or component construction to perform a load-carrying or other operational function, in addition to ballistic protection.

Kill - A condition of system or component failure due to a weapon effect.

Kill level - A specific condition (or level) of weapon effect damage that precludes continued flight or ability to accomplish the mission objective.

Leg contour envelope - A method for graphically depicting the contours of a man's leg and of body armor for the vertical and horizontal profiles of the leg.

Lethality - A measure of the destructive effect of a particular projectile on a given target under specified attack conditions.

Masking - A screen or aircraft structure or components between some point of interest and the attacking projectile.

Maximum vulnerable range - The range beyond which a specific threat is incapable of defeating a given armor.

Merit rating (velocity) - $\frac{V_x \text{ candidate armor}}{V_x \text{ standard armor}}$

V_x = protection ballistic limit

Merit rating (weight) - $\frac{\text{Areal density (standard armor)}}{\text{Areal density (candidate armor)}} \times 100$

Mission essential - That which is essential to the satisfactory completion of a specific mission.

Modular armor - An armor system designed to give protection to an element and which encloses the element within a periphery of armor.

Multihit capability - The ability of an armor to sustain two or more hits within a distance of 3 calibers without loss of ballistic performance.

Natural armor - Nonarmor material interposed between a point of interest and the weapon effect.

Natural masking - See natural armor.

Navy ballistic limit - Ballistic protection criteria developed by the U.S. Navy.

Nonballistic properties - The physical properties of an armor material or system other than the threat-defeat qualities.

Parasitic armor - Armor installed on an aircraft, with no other purpose than ballistic protection.

Passive defense - Aircraft defense derived from its physical resistance to projectile impact damage.

Penetrator - The core or that part of an armor-piercing projectile designed to penetrate to the interior of a target.

Petalling - Plastic deformation of a ductile material when struck by an impacting projectile, resulting in material being forced outward in leaflike or petal forms.

Primary damage effect - That damage directly resulting from the projectile impact and penetration (i.e., structural breakdown, spallation, incendiary-caused fire, etc).

P_H - The probability of a hit on the target.

$P_{K/H}$ - The probability of kill given a hit.

P_K - The probability of kill.

$$P_K = P_H \cdot P_{K/H}$$

Projectile - The ballistic element fired from a gun system.

Projectile aspect angle - The angle between the normal of the target plane surface and the line of travel of a projectile.

Protection ballistic limit - Criteria for ballistic limit of a material.

Protection (V_{50}) ballistic limit - A limit established for a given material against a specific threat under specified standard test conditions where 50 percent of penetrators are defeated.

Punching - A material failure in shear evidenced by a circular plug about the size of the attacking projectile being forced out of the material.

Rachel net - A type of net mesh used in aircrew personal equipment to provide maximum mobility and comfort.

Reticulated foam - A flexible open-pore foam with a netlike porous structure.

Scupper - Perforations in the lower portions of an enclosure for the drainage of unwanted fluid.

Secondary damage effects - That damage not directly caused by projectile impact (i.e., fire, explosion, spallation, etc).

Small arms, small-arms systems - Weapon systems for projectiles smaller in size than 20 mm.

Solid armor - Homogenous and composite armor materials and systems having no air space between elements.

Spaced armor - Armor systems having spaces between armor elements.

Spalling - Detachment or delamination of material as a result of projectile impact, usually from the rear face.

Stoichiometric mixture - A proportional mixture of materials whose chemical reaction leaves no uncombined residue (i.e., complete combustion of a flammable material).

Striking velocity - Relative velocity between projectile and target at the instant of impact.

Survivability - That measure of an aircraft's capability to continue to function after being hit by hostile weapon systems. This includes those design and performance features that enable an aircraft, by avoidance or suppression techniques, to degrade the ability of a hostile force to use its weapons effectively.

Survivability enhancement - Those techniques and methods which improve the probability of survival.

Tension web system - Integrates rachel net with other fabric elements of a body armor suspension system.

Threat, hostile weapons - Enemy force equipment used to produce hostile environments.

Triskelion - A figure consisting of three branches radiating in a spiral from a center.

V_X ballistic limit - The velocity at which X percent of penetrator impacts make complete penetration.

V_{50} ballistic limit - The velocity at which 50 percent of the impacts are found to complete penetration.

Vertical contour envelope - A method for graphically depicting the contours of a man's body and of body armor for the vertical profiles.

Vulnerability - That quantitative measure of an aircraft's response to a given hostile weapon effect, and the encounter condition, that result in attrition, aircrew injury, or inability to perform those functions essential to achieve combat mission objectives.

Vulnerability assessment - The process used to describe the target vulnerability to specific weapon effects, usually expressed in square feet for specific attack directions.

Weapon effects - The terminal damage mechanisms at or near the target, which results in system damage or degraded capability.

Unyawed projectile - The projectile attitude, with respect to its line of flight at the moment of target impact, is less than 5 degrees.

S-N curve - A graphical presentation of the number of cycles an element can sustain at a given level of stress before failure.

"Zippering effects" - Rapid crack propagation of a material along a line of fastener holes or other in-line stress concentration points.

APPENDIX I

SMALL-ARMS THREAT INFORMATION

1.1 INTRODUCTION

This appendix contains additional unclassified data on hostile small-arms weapons and projectiles, supplementing the basic information in paragraphs 2.2 and 2.3, respectively. Volume II (USAAMRDL Technical Report 71-41B) contains classified data on projectiles and ballistics that are useful for survivability/vulnerability analyses.

1.2 SMALL-ARMS WEAPONS

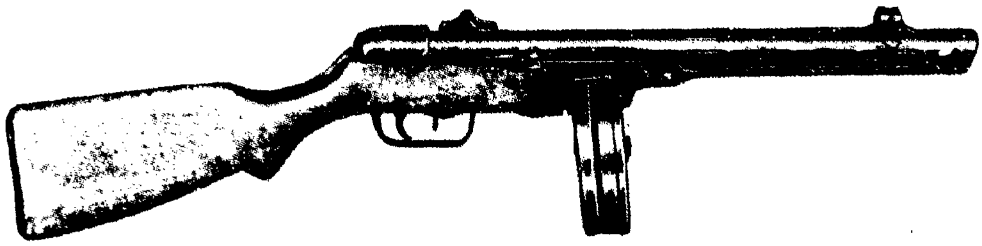
Figures 168 through 182 contain pertinent data on representative types of small-arms weapons used by the Communist Bloc countries.

1.3 SMALL-ARMS PROJECTILES

Figures 183 through 194 contain basic information on representative small-arms projectiles predominantly used for small-arms weapons.

NOMENCLATURE: 7.62-mm Submachinegun Model 1941, Shpagin (PPSh) COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 7.62 ММ ПИСТОЛЕТ-ПУЛЕМЕТ ОБР. 1941 Г. (ППШ) ADOPTED: 1941



The Shpagin submachinegun, standardized in 1941, was developed by George S. Shpagin, a noted Soviet small-arms designer. It combines several good features of previous Soviet and foreign designs. Considerable thought was also given to manufacturing considerations, and workmanship is consequently generally crude on nonfunctional parts.

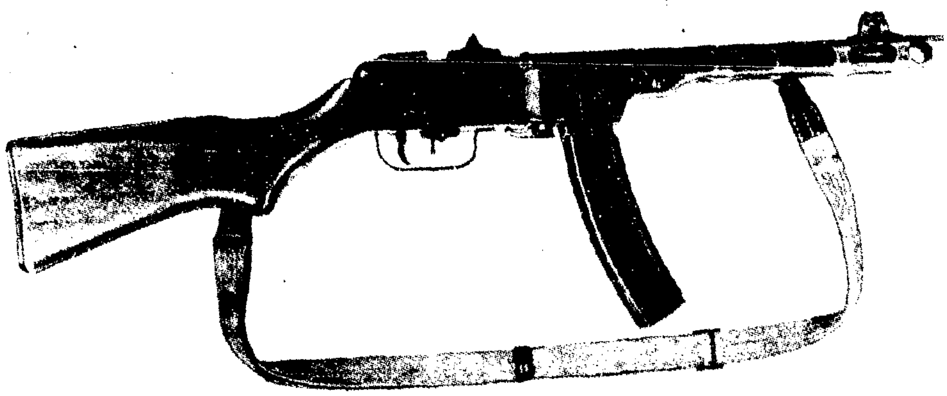
The receiver cover and barrel jacket are a single pressing, which also incorporates a simple, built-in, combined muzzle brake and compensator. The bolt has a fixed firing pin and a one-piece extractor. When this weapon was first issued, only the drum magazine was used; but later the 35-round, curved magazine was provided, probably because of deficient performance by the drum.

CURRENT STATUS:	Obsolete in U.S.S.R.
USING COUNTRIES:	Albania, Bulgaria, Hungary, Poland, Rumania, East Germany, Communist China, North Korea, North Vietnam, Afghanistan
WEAPON:	
Caliber	7.62 mm
Operation-type	Blowback
Fire-type	Selective
Cyclic rate	900 rpm
Length overall	
-w/stock extended	33 in.
-w/stock retracted	Does not apply
Weight-loaded w/drum	11.5 lb
-unloaded w/drum	9.75 lb
Aprx. practical range	300 m
Aprx. muzzle velocity	1650 fps
FEED:	
Type	Drum or box magazine
Location	Under receiver
Capacity	Drum, 71 rd; box, 35 rd
Magazine release location	Rear of magazine housing
Magazine weight-loaded	Drum, 4 lb; box, 1.5 lb
-unloaded	Drum, 2.25 lb; box, 0.5 lb
BARREL:	
Length	10.5 in.
Flash hider-type	Does not apply
Muzzle brake-type	Combined with compensator
Compensator-type	Integral with barrel jacket
SIGHTS:	
Front-type	Flat-top post
Rear-type	L-flip
ACTION:	
Locking feature-type	None
Trigger-type	Spur
Safety-type	Latch, locking bolt in open and closed positions
Selector-type	Sliding lever in front of trigger
STOCK:	
Type	Half pistol grip
Material	Wood

Figure 168. 7.62-MM Shpagin Submachinegun Model 1941 (PPSH).

NOMENCLATURE: 7.62-mm Submachinegun Type 50 COUNTRY: Communist China

NATIVE DESIGNATION: ? ADOPTED: 1950



The Chinese Communist 7.62-mm submachinegun Type 50 is a slightly modified copy of the obsolete Soviet 7.62-mm Model 1941 (PPSh) submachinegun. The changes which help to differentiate the Chinese Communist and Soviet weapons are: apertures, rather than "V" notches, in the rear sight; a rubber, rather than a plastic impregnated fiber, buffer; and the use of box magazines.

These weapons were used by all units of the Chinese Communist Army, but are now being replaced by the Type 56 assault rifle. The Type 50 submachinegun, however, is still in wide use by some army units, security forces, naval forces, and militia units. It has been supplied to North Vietnamese troops, who call it the K-50 submachinegun.

CURRENT STATUS:	Ltd standard
USING COUNTRIES:	Communist China, North Korea, North Vietnam, Cuba
WEAPON:	
Caliber	7.62 mm
Operation-type	Blowback
Fire-type	Selective
Cyclic rate of fire	900 rpm
Practical rate of fire-auto	70 to 100 rpm
-semiauto	30 rpm
Length overall	33 in.
-w/stock retracted	Does not apply
Weight-loaded	9 lb
-unloaded w/mag	8 lb
Effective combat range-auto	100 m
-semiauto	200 m
FEED:	
Type	Box magazine
Location	Under receiver
Capacity	35 rd
Magazine release location	Rear of magazine housing
Magazine weight-loaded	1.5 lb
-unloaded	0.5 lb
BARREL:	
Length	10.5 in.
Flash hider-type	Does not apply
Muzzle brake-type	Combined with compensator
Compensator-type	Integral with barrel jacket
Aprx. muzzle velocity	575 m/s
SIGHTS:	
Front-type	Protected post
Rear-type	L-flip w/aperture
ACTION:	
Locking feature-type	None
Trigger-type	Spur
Safety-type	Latch locks bolt open or closed
-location	On operating handle
Selector-type	Sliding lever in front of trigger
STOCK:	
Type	Fixed
Material	Wood
AMMUNITION:	
Type	Chinese Communist 7.62 x 25 ball cartridges.

Figure 169. 7.62-MM Submachinegun Type 50.

NOMENCLATURE: **7.62-mm Submachinegun Model 1943 (PPS)** COUNTRY: **U.S.S.R.**

NATIVE DESIGNATION: 7,62 ММ ПИСТОЛЕТ-ПУЛЕМЕТ ОБР. 1943 Г. (ППС) ADOPTED: 1943

The PPS-43 is the last of the standard Soviet pistol-caliber submachineguns. In spite of its crude finish, this weapon combines the best characteristics of earlier models. Low cyclic rate, light weight, better balance, and overall reliability make this weapon superior to its predecessors. It has been replaced in the Soviet Army, however, by the AK assault rifle.

An experimental version of this weapon, designed by Sudaev, was fabricated and issued for limited troop testing in 1942. Based on combat experience, engineering improvements were incorporated, and it was standardized in 1943. The principal improvements were the substitution of a 35-round magazine for the previous 32-round magazine, front sight adjustment simplified, stock easier to fold or extend, and a better safety device.

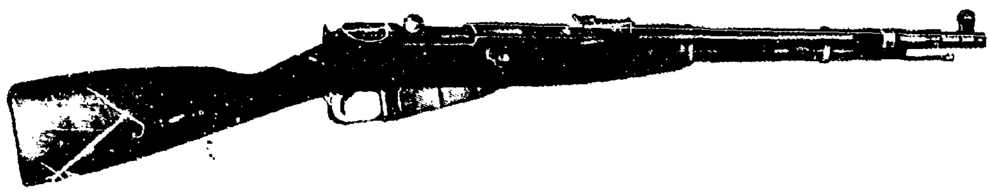
The PPS-43 is of all-metal construction (except for plastic grips), and uses a curved box magazine which cannot be used in any other Soviet submachinegun. It fires either the Soviet 7.62-mm M1930 "P" pistol ball or "P-41" API submachinegun rounds, and will also accept 7.63-mm Mauser pistol ammunition.

CURRENT STATUS:	Obsolete in U.S.S.R.
USING COUNTRIES:	Bulgaria, Hungary, North Korea, North Vietnam, Communist China
WEAPON:	
Caliber	7.62 mm
Operation-type	Blowback
Fire-type	Automatic
Cyclic rate	650 rpm
Length overall -w/stock extended	37.7 in.
-w/stock retracted	24.25 in.
Weight-loaded	8.25 lb
-unloaded w/mag.	7.5 lb
Aprx. practical range	200 m
Aprx. muzzle velocity	1640 fps
FEED:	
Type	Box magazine
Location	Under receiver
Capacity	35 rd
Magazine release location	Rear of magazine housing
Magazine weight-loaded	1.25 lb
-unloaded	0.5 lb
BARREL:	
Length	9.5 in.
Flash hider-type	Does not apply
Muzzle brake-type	Single baffle
Compensator-type	Combined with muzzle brake
SIGHTS:	
Front-type	Post
Rear-type	L-flip w/notch
ACTION:	
Locking feature-type	None
Trigger-type	Spur
Safety-type	Latch below receiver, at front of trigger guard, to lock bolt
Selector-type	Does not apply
STOCK:	
Type	Folding
Material	Metal

Figure 170. 7.62-MM Submachinegun Model 1943 (PPS).

NOMENCLATURE: 7.62-mm Carbine M1944 — COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 7.62 ММ КАРАБИН ОБР. 1944 Г. — ADOPTED: 1944



The Soviet M1944 carbine was adopted near the end of World War II as the standard shoulder weapon of all Soviet troops except naval personnel, security troops, and snipers. It was adopted after combat experience had shown that the M1891/30 rifle was too long and unwieldy. It is essentially a shortened rifle with a permanently attached folding bayonet.

This weapon is the last of the series of bolt-action rifles and carbines based on the design developed by Colonel S.I. Mosin of the Imperial Russian Army, employing the magazine originated by the Belgian, Nagant. The Mosin-Nagant system suffers from an overcomplicated bolt, but in other respects is relatively simple to service and maintain. The safety, in that it is extremely hard to engage and disengage, represents a shortcoming of these weapons.

CURRENT STATUS:	Obsolete in U.S.S.R.
USING COUNTRIES:	Albania, Bulgaria, Hungary, Rumania, Poland, East Germany, Communist China, North Korea, North Vietnam, Afghanistan
WEAPON:	
Caliber	7.62 mm
Operation-type	Bolt action
Fire-type	Manual
Cyclic rate	Does not apply
Length overall w/o bayonet	40 in.
Weight-loaded	8.85 lb
-unloaded	8.6 lb
Aprx. max. hor. range	3200 m
FEED:	
Type	Magazine
Location	Integral
Capacity	5 rd
Magazine release location	Does not apply
BARREL:	
Length	20.47 in.
Flash hider-type	Does not apply
Muzzle brake-type	Does not apply
Compensator-type	Does not apply
Aprx. muzzle velocity w/ light ball	2690 fps
SIGHTS:	
Front-type	Post
Rear-type	Tangent leaf
Rear sight-graduation	0 to 10 (0 to 1000 m)
-adjustment	Curved ramp
Optical sight-type	Does not apply
-power	Does not apply
ACTION:	
Locking feature-type	Rotating bolt
Bolt position-manual	Closed
-semiautomatic	Does not apply
-full automatic	Does not apply
Trigger-type	Spur
Safety-type	Rotating cocking piece
-location	Rear of bolt
STOCK:	
Type	Straight
Material	Wood

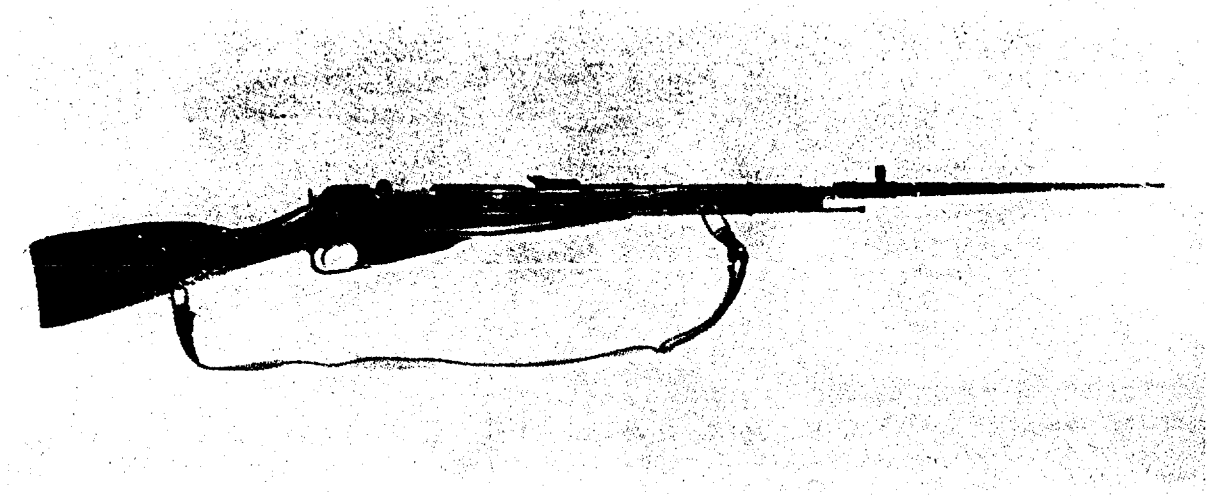
Figure 171. 7.62-MM Carbine M1944.

NOMENCLATURE: 7.62-mm Carbine Type 53

NATIVE DESIGNATION: ?

COUNTRY: Communist China

ADOPTED: 1953



The Chinese Communist carbine Type 53 is a copy of the obsolete Soviet 7.62-mm carbine Model 1944. Although no longer found in Chinese Communist first-line units, it is still used by second-line, militia, and security forces, and has been distributed as military aid to some nations.

This weapon is easily recognized by its permanently attached folding cruciform bayonet; prominent magazine; and short, straight, bolt handle. The safety on this weapon is extremely difficult to engage or disengage; the cocking piece must be drawn back against the force of the powerful, compressed mainspring and then rotated to the left.

CURRENT STATUS:	Ltd standard
USING COUNTRIES:	Communist China, North Korea, North Vietnam, Cuba
WEAPON:	
Caliber	7.62 mm
Operation-type	Bolt action
Fire-type	Manual
Cyclic rate of fire	Does not apply
Practical rate of fire	8 to 10 rpm
Length overall	40 in w/bayonet folded
Weight-loaded	8.86 lb
-unloaded	8.6 lb
Aprx. max. hor. range	3200 m
Effective combat range	500 m
FEED:	
Type	Magazine
Location	Integral
Capacity	5 rd
Magazine release location	Does not apply
BARREL:	
Length	20.47 in
Flash hider-type	Does not apply
Muzzle brake-type	Does not apply
Compensator-type	Does not apply
Aprx. muzzle velocity	810 m/s
SIGHTS:	
Front-type	Protected post
Rear-type	Tangent leaf
Rear sight-graduation	0 to 10 (0 to 1000 m)
-adjustment	Elevation
Optical sight-type	Does not apply
-power	Does not apply
ACTION:	
Locking feature-type	Rotating bolt
Bolt position-manual	Closed
-semiautomatic	Does not apply
-full automatic	Does not apply
Trigger-type	Spur
Safety-type	Rotating cocking piece
-location	Rear of bolt
STOCK:	
Type	Fixed
Material	Wood
AMMUNITION:	
Type	Chinese Communist 7.62 x 54R cartridges of various types.

Figure 172. 7.62-MM Carbine Type 53.

NOMENCLATURE: 7.62-mm Assault Rifle Model AK-47 COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 7.62 MM АВТОМАТ КАЛАШНИКОВА (AK-47) ADOPTED: 1947

The Soviet 7.62-mm assault rifle Model AK-47 with fixed wooden stock was the basic individual infantry weapon of the Soviet Army until the introduction in about 1958 of the AKM, a major modification of the AK-47. It is chambered for the Model 43 intermediate cartridge. The weapons, which has a chrome-plated bore, performed well in a test conducted at Aberdeen Proving Ground in 1956.

The AK is a selective-fire weapon that can be fired either semiautomatically or automatically. A pivoted, plate-shaped, safety-selector lever on the right side of the receiver allows the user to make this selection, the designation "СД" indicating semiautomatic fire, and "АВ" indicating automatic fire. When this lever is in the uppermost (safe) position, the trigger is prevented from moving. When in the "safe" position, the lever closes the operating-handle slot in the receiver cover, preventing entry of foreign matter into the receiver.

<u>CURRENT STATUS</u>:	Ltd standard
<u>USING COUNTRIES</u>:	U.S.S.R. and most Bloc countries
<u>WEAPON</u>:	
Caliber	7.62 mm
Operation-type	Gas
Fire-type	Selective
Cyclic rate	600 rpm
Length overall	34.2 in.
Weight-loaded	10.58 lb
-unloaded	9.48 lb
Aprx. max. hor. range	2500 m
<u>FEED</u>:	
Type	Box magazine
Location	Under receiver
Capacity	30 rd
Magazine release location	Rear of magazine housing
<u>BARREL</u>:	
Length	16.3 in.
Flash hider-type	Does not apply
Muzzle brake-type	Does not apply

Compensator-type	Does not apply
Aprx. muzzle velocity	2329 fps
<u>SIGHTS</u>:	
Front-type	Protected post
Rear-type	Tangent leaf w/U notch
Rear sight-graduation	1 to 8 (100 to 800 m) in 100-m increments
-adjustment	Elevation
Optical sight-type	Does not apply
-power	Does not apply
<u>ACTION</u>:	
Locking feature-type	Rotating bolt
Bolt position-manual	Does not apply
-semiautomatic	Closed
-full automatic	Closed
Trigger-type	Spur
Safety-type	Pivoted plate
-location	Right side of receiver
<u>STOCK</u>:	
Type	Fixed
Material	Wood

Figure 173. 7.62-MM Assault Rifle Model AK-47.

NOMENCLATURE: 7.62-mm Assault Rifle Model AKM | COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 7,62 ММ АВТОМАТ КАЛАШНИКОВА МОДЕРНИЗИРОВАННЫЙ (АКМ) | ADOPTED: 1961 ?

For the past several years, a number of reports indicated that a lighter version of the Soviet AK-47 assault rifle had come into service. The nomenclature "AKM" was associated with the weapon, the letter "M" being the initial for the Soviet word indicating "modernized."

Recent acquisition, test, and evaluation of an AKM rifle discloses that it differs from the AK-47 rifle in the following respects:

(1) The AKM has a stamped receiver with bolt guides welded to the inside walls, as distinct from the machined receiver used on the AK-47.

(2) On the AKM the handguard, the forearm, the pistol grip, and the buttstock are of laminated wood, as compared to solid wooden components on the AK-47. The AKM forearm also contains a bulge which provides the rifleman with a better grip.

(3) The gas cylinder on the AKM has four ports (two on each side), as compared to eight on the AK-47 (four on each side). The gas ports of the AKM are at the forward end of the gas-cylinder tube.

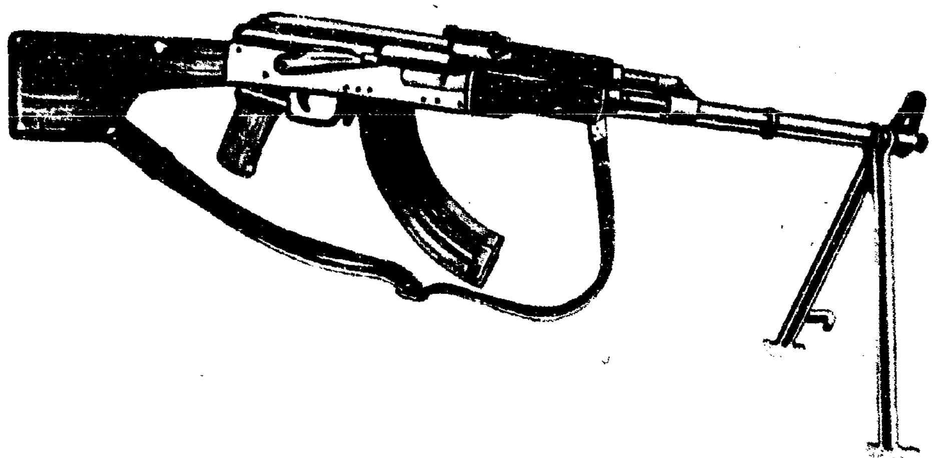
CURRENT STATUS:	Standard
USING COUNTRIES:	U.S.S.R.
WEAPON:	
Caliber	7.62 mm
Operation-type	Gas
Fire-type	Selective
Cyclic rate	640 rpm aprx.
Length overall	34.5 in.
Weight-loaded w/o bayonet	8.87 lb
-unloaded w/o mag. & sling	6.95 lb
Aprx. max. hor. range	2500 m
FEED:	
Type	Box magazine
Location	Under receiver
Capacity	30 rd
Magazine release location	Rear of magazine housing
BARREL:	
Length	16.3 in.
Flash hider-type	Does not apply
Muzzle brake-type	Does not apply

Compensator-type	Does not apply
Aprx. muzzle velocity	710 m/s
SIGHTS:	
Front-type	Protected post
Rear-type	Tangent leaf w/U notch
Rear sight-graduation	1 to 10 (100 to 1000 m) in 100-m increments
-adjustment	Elevation
Optical sight-type	Does not apply
-power	Does not apply
ACTION:	
Locking feature-type	Rotating bolt
Bolt position-manual	Does not apply
-semiautomatic	Closed
-full automatic	Closed
Trigger-type	Spur
Safety-type	Pivoted plate
-location	Right side of receiver
STOCK:	
Type	Fixed
Material	Laminated wood

Figure 174. 7.62-MM Assault Rifle Model AKM.

NOMENCLATURE: 7.62-mm Light Machinegun Model RPK COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 7.62 ММ РУЧНОЙ ПУЛЕМЕТ КАЛАШНИКОВА (РПК) ADOPTED: 1961 ?



The Soviet 7.62-mm light machinegun Model RPK is now the standard squad automatic weapon of the Soviet Armies, having replaced the 7.62-mm light machinegun Model RPD. It will certainly be adopted by other Communist Bloc countries except Czechoslovakia.

The RPK is essentially the Soviet AK-47 assault rifle, but differs from the AK-47 in having a longer barrel, a bipod, and a shoulder stock similar to that of the RPD light machinegun.

A circular, spring-actuated drum magazine, holding 75 rounds, and a curved box magazine, holding 40 rounds, are provided. The weapon fires the standard Soviet 7.62-mm M1943 cartridge.

The RPK undoubtedly has proved to be more reliable than the RPD, the latter having never been quite satisfactory for the Soviets even though it was modified several times to improve its reliability. The adoption of the RPK reduces to one the number of small-arms systems in the Communist Bloc infantry squad, thus simplifying parts interchangeability.

CURRENT STATUS:	Standard
USING COUNTRIES:	U.S.S.R., East Germany
WEAPON:	
Caliber	7.62 mm
Operation-type	Gas
Fire-type	Selective
Cyclic rate	600 rpm
Length overall	40.5 in. ?
Weight unloaded-w/box	11 lb
-w/drum	12.35 lb
Aprx. muzzle velocity	2411 fps
Aprx. max. hor. range	2500 m
FEED:	
Type	Box or drum magazine
Location	Under receiver
Capacity	Box, 40 rd; drum, 75 rd

BARREL:	
Cooling	Air
Length	21 in. ?
Barrel change	No
SIGHTS:	
Front-type	Protected post
Rear-type	Tangent leaf w/U notch
Optical sight-type	Does not apply
-power	Does not apply
ACTION:	
Locking feature-type	Rotating bolt
MOUNT:	
Type	Bipod
Weight	?

Figure 175. 7.62-MM Light Machinegun Model RPK.

NOMENCLATURE: 7.62-mm Light Machinegun Model DPM

COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 7.62 ММ ДЕГТЯРЕВА ПЕХОТНЫЙ МОДЕРНИЗИРОВАННЫЙ (ДПМ)

ADOPTED: 1944

The DPM (modernized Degtyarev infantry) machinegun replaced the DP machinegun in the Soviet Army. The DP, because of the location of its driving spring, could not withstand continuous firing. The DPM is basically a DP with its driving spring relocated to the rear of the receiver, away from barrel heat. It also has a pistol grip for improved control during firing.

The DPM was replaced in the Soviet Army by the RPD light machinegun. An exact copy, except for its markings, was produced in Communist China as the Type 53 light machinegun. Both the DPM and Type 53 weapons are in extensive use, both in Eurasian Communist second line units and Communist-oriented irregular forces.

CURRENT STATUS: ---------- Obsolete	BARREL:
USING COUNTRIES: ---------- Albania, Bulgaria, Hungary, Rumania, East Germany, Communist China, North Korea, Poland, North Vietnam, Afghanistan	Cooling ---------------- Air
	Length ----------------- 23.8 in.
	Barrel change ---------- Yes
	Aprx. muzzle velocity -- 825 meters per second with type LPS ball, 840 meters per second with light ball M1908 type L.
WEAPON:	SIGHTS:
Caliber ------------------ 7.62 mm	Front-type ------------- Hooded post
Operation-type ----------- Gas	Rear-type -------------- Tangent leaf w/U notch
Fire-type ---------------- Automatic	Optical sight-type ----- Does not apply
Cyclic rate of fire ------ 600 rpm	-power ---------------- Does not apply
Practical rate of fire --- 80 rpm	
Length overall ----------- 50 in.	ACTION:
Weight-loaded ------------ 26.9 lb	Locking feature-type --- Dual flaps
-unloaded w/o mag. ------ 20.9 lb	
Aprx. max. hor. range ---- 3050 m	MOUNT:
Effective ground combat range ------------------ 800 m	Type ------------------- Bipod
Effective AA slant range - Does not apply	Weight ----------------- 1.4 lb
FEED:	AMMUNITION: ------------ Soviet 7.62 x 54R cartridges of various types.
Type --------------------- Drum magazine	
Location ----------------- Top of receiver	
Capacity ----------------- 47 rd	

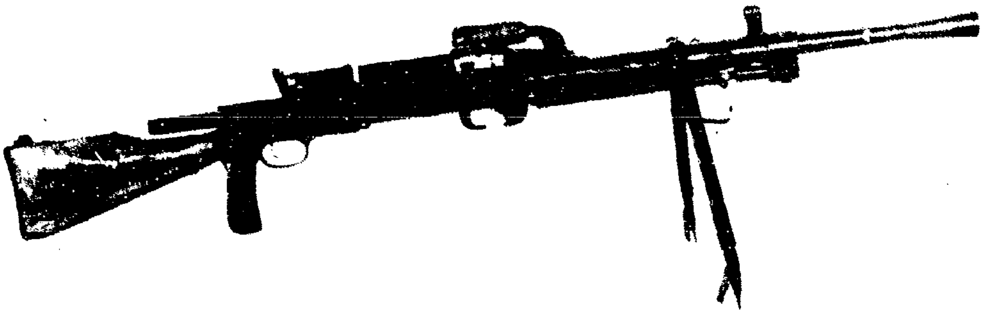
Figure 176. 7.62-MM Light Machinegun Model DPM.

NOMENCLATURE: 7.62-mm Company Machinegun Model RP-46

COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 7,62 ММ РОТНЫЙ ПУЛЕМЕТ-46 (РП-46)

ADOPTED: 1946



The Soviet RP-46 (Company Machinegun Model 1946) machinegun was designed as a result of Soviet World War II experiences. The SG-43 heavy machinegun, while capable of delivering sustained fire, was too heavy and bulky for a fluid combat situation. The DPM machinegun although light in weight and mobile, was limited in the amount of fire it could deliver by its 47-round magazine capacity and its light barrel which did not give sufficient stabilization or heat absorption for sustained fire. The RP-46 is a compromise between these two weapons.

The RP-46 is a rifle-company-level weapon. It is a development of the DTM with a heavy barrel; a relocated, modified bipod; and a belt-feed mechanism. For ease in movement, a carrying handle is provided.

The feed mechanism is operated by the operating handle moving back and forth during firing. This mechanism is held on the RP-46 by the same devices that hold the pan magazine on the DTM: a "T" lug on the barrel jacket and the regular magazine catch. The operating handle, when vertical, also aids in locking the feed mechanism to the receiver. If the feed mechanism is removed, the 47-round pan magazines of the DP and DPM machineguns may be used for feeding.

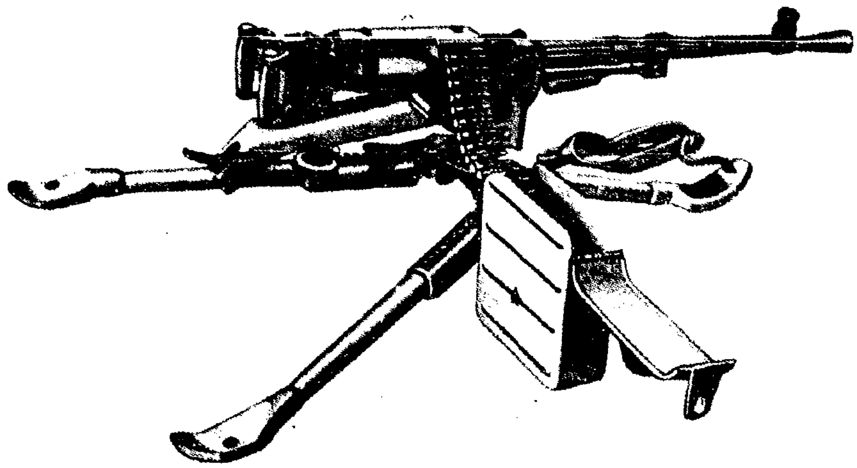
CURRENT STATUS:	Obsolete
USING COUNTRIES:	Albania, Bulgaria, Hungary, Rumania, East Germany, Communist China, North Korea, Poland, North Vietnam, Afghanistan
WEAPON:	
Caliber	7.62 mm
Operation-type	Gas
Fire-type	Automatic
Cyclic rate of fire	600 rpm
Practical rate of fire	230 to 250 rpm
Length overall	50.5 in.
Weight-loaded	Does not apply
-unloaded	29.75 lb
Aprx. max. hor. range	3500 m
Effective ground combat range	1000 m
Effective AA slant range	Does not apply
FEED:	
Type	Belt or drum magazine
Location	Belt, right to left; drum, top of receiver
Capacity	Belt, 250 rd; drum, 47 rd

BARREL:	
Cooling	Air
Length	23.9 in.
Barrel change	Yes
Aprx. muzzle velocity	840 m/s
SIGHTS:	
Front-type	Protected post
Rear-type	Tangent leaf w/U notch
Optical sight-type	Does not apply
-power	Does not apply
ACTION:	
Locking feature-type	Dual flaps
MOUNT:	
Type	Bipod
Weight	?
AMMUNITION:	**Soviet 7.62 x 54R cartridges of various types.**

Figure 177. 7.62-MM Company Machinegun Model RP-46.

NOMENCLATURE: 7.62-mm Heavy Machinegun Model SGM COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 7,62 ММ СТАНКОВЫЙ ПУЛЕМЕТ СИСТЕМЫ ГОРЮНОВА МОДЕРНИЗИРОВАННЫЙ ОБР. 1943 Г. (СГМ) ADOPTED: 1946



The Soviet 7.62-mm heavy machinegun Model SGM is the battalion-level, rifle-calibered machinegun. It is gas operated, and is chambered for the 7.62-mm rimmed cartridge, which is ballistically similar to the U.S. caliber .30 round.

The SGM is a postwar modification of the SG-43, differing from the latter as follows: (1) It has a longitudinally fluted barrel, (2) the barrel lock has been redesigned to permit head-space adjustment, and (3) two new mounts have been designed, both of which can be set up for antiaircraft firing.

Like most Soviet machineguns, the SGM fires from the open-bolt position, and is fed from the right side by a metallic nondisintegrating link belt with a capacity of 250 rounds. The high practical rate of fire of the SGM, 250 to 300 rounds per minute, is due to its heavy (9-pound) barrel.

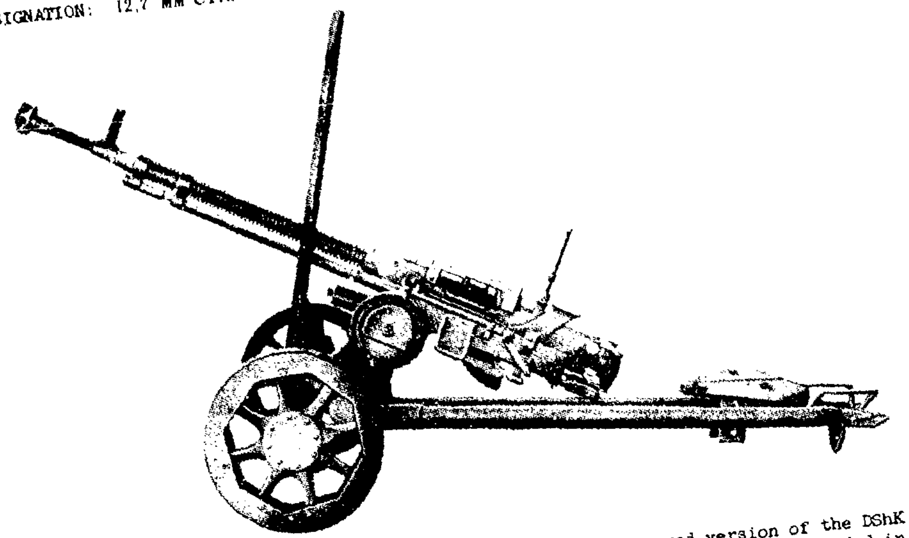
CURRENT STATUS: --------- Standard	BARREL:
USING COUNTRIES: -------- U.S.S.R., Bulgaria, Rumania, Poland, East Germany	Cooling ---------------- Air
	Length ----------------- 28.3 in. aprx
	Barrel change ---------- Yes
WEAPON:	SIGHTS:
Caliber ----------------- 7.62 mm	Front-type ------------- Protected post
Operation-type ---------- Gas	Rear-type -------------- Leaf
Fire-type --------------- Automatic	Optical sight-type ----- Does not apply
Cyclic rate ------------- 600 to 700 rpm	-power ---------------- Does not apply
Length overall ---------- 44.1 in. aprx.	ACTION:
Weight unloaded w/o belt -------------- 29.8 lb	Locking feature-type --- Rotating bolt
Aprx. muzzle velocity --- 2625 fps	MOUNT:
Aprx. max. hor. range --- 3000 m	Type ------------------- Tripod or wheeled carriage
FEED:	Weight ----------------- Tripod, 30.5 lb; carriage, 50.9 lb
Type -------------------- Metallic nondisintegrating link belt	
Location ---------------- Right side of receiver	
Capacity ---------------- 250 rd	

Figure 178. 7.62-MM Heavy Machinegun Model SGM.

COUNTRY: U.S.S.R.

NOMENCLATURE: 12.7-mm Heavy Machinegun Model 38/46 DShK ADOPTED: 1946

NATIVE DESIGNATION: 12,7 ММ СТАНКОВЫЙ ПУЛЕМЕТ ОБР. 1938/46 Г. (ДШК)



The Soviet 12.7-mm DShK heavy machinegun Model 38/46 is an improved version of the DShK M38. Originally intended as a ground-mounted, antiaircraft gun, the M38/46 has been superseded in that role by the 14.5-mm ZPU series of weapons (FOM-2-1005-4.14.5-2 and -3). It is still used, however, as antipersonnel and antiaircraft armament on tanks, assault guns, and armored personnel carriers. The M38/46 is mounted coaxially with the main gun of the T-10 heavy tank.

As an antiaircraft gun, the M38/46 has an effective vertical range of about 915 meters (1000 yards). When multiply mounted, it is quite effective against relatively low and slow aircraft such as helicopters.

CURRENT STATUS: --------- Standard

USING COUNTRIES: -------- U.S.S.R. and all Bloc countries, and Afghanistan, Syria, Indonesia, Egypt, Iraq, Cuba

WEAPON:
Caliber ----------------- 12.7 mm
Operation-type ---------- Gas
Fire-type --------------- Automatic
Cyclic rate ------------- 540 to 600 rpm
Length overall ---------- 62.5 in.
Weight unloaded
 w/o belt --------------- 78.5 lb
Aprx. muzzle velocity --- 2822 fps
Aprx. max. hor. range --- 7000 m

FEED:
Type -------------------- Metallic nondisintegrating link belt
Location ---------------- Left side of receiver
Capacity ---------------- 50 rd

BARREL:
Cooling ----------------- Air
Length ------------------ 42.1 in.
Barrel change ----------- No

SIGHTS:
Front-type -------------- Protected post
Rear-type --------------- Folding leaf w/U notch
Optical sight-type ------ Does not apply
 -power ----------------- Does not apply

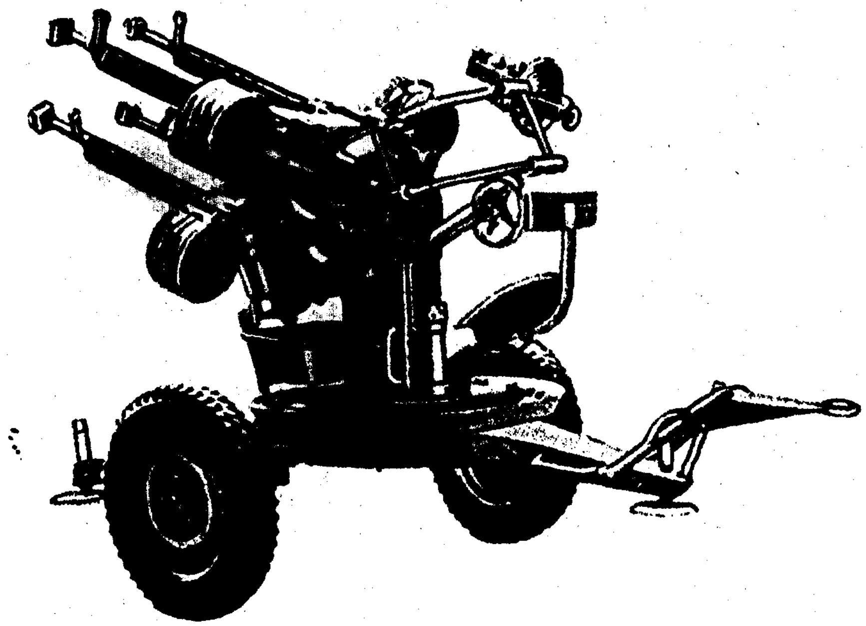
ACTION:
Locking feature-type --- 2 pivoting flaps

MOUNT:
Type -------------------- Two-wheeled carriage
Weight ------------------ 269 lb

Figure 179. 12.7-MM Heavy Machinegun Model 38/46.

NOMENCLATURE: **Quad 12.7-mm Antiaircraft Heavy Machinegun** COUNTRY: **Czechoslovakia**

NATIVE DESIGNATION: ? ADOPTED: 1956



This antiaircraft machinegun consists of four Soviet-designed, Czechoslovak-manufactured, 12.7-mm heavy machineguns Model 38/46 (FOM-2-1005-4-12.7-3) mounted on a Czechoslovak-designed and Czechoslovak-built carriage. The four basic guns, like their Soviet prototype, are gas-operated, air-cooled weapons initially intended as protection against low-level air attack; however, they are also highly effective in a ground role against personnel and lightly armored vehicles. The weapon can track targets flying at speeds of up to 250 meters per second (486 knots).

The carriage has two detachable wheels, a pedestal to which the four guns are attached, a base with leveling jacks, and a single bucket seat for the gunner, who traverses, elevates, sights, and fires the weapon. A handwheel is used to elevate or depress the four guns. The weapon is traversed when the gunner presses his feet against the mount base to rotate the mount pedestal on its roller bearings.

The ring-type sight features an articulated mounting frame which allows the sight and guns to move synchronously.

The primary disadvantage of this weapon is the small capacity of its ammunition drums, which limits the maximum engagement time without reloading to approximately 1 second.

Figure 180. Quad 12.7-MM Antiaircraft Heavy Machinegun.

NOMENCLATURE: **Quad 12.7-mm Antiaircraft Heavy Machinegun**

CURRENT STATUS:	?
WEAPON:	
Weight-firing position	1331 lb ?
-traveling position	1411 lb
Length overall-travel. pos.	9.5 ft
Width overall-travel. pos.	5.2 ft
Height overall-travel. pos.	5.1 ft w/o sights
GUN:	
Caliber	12.7 mm
Length of barrel	42.1 in.
Operation-type	Gas
Fire-type	Automatic
Cyclic rate of fire	540 to 600 rpm per gun
Practical rate of fire	80 rpm per gun
FEED:	
Type	Metallic non-disintegrating link belt
Location	Either side of receiver
Capacity	50 rd
FIRE CONTROL:	
On carriage	Optical, speed ring
Off carriage	None
SIGHTS:	
Front-type	Does not apply
Rear-type	Upper two guns retain standard rear sights for emergency ground fire.
Optical sight-type	Telescope for ground fire only.
-power	2.5 power
PERFORMANCE:	
Elevation	-7 to +90 deg
Traverse	360 deg
Aprx. max. vert. range	4400 m
Aprx. max. hor. range	6500 m
Effective AA slant range	1000 m (max)
Aprx. muzzle velocity	840 m/s
Armor penetration	17 mm at 0 deg at 500 m
ACTION:	
Locking feature-type	Dual flaps
CARRIAGE (MOUNT):	
Type	Towed two-wheeled dual purpose
Wheels-Nr.	2
Tires-type	Pneumatic
PROJECTILES:	
Types	API and API-T Czechoslovak ammunition believed to be identical to Soviet ammunition.

Figure 180. Quad 12.7-MM Antiaircraft Heavy Machinegun (Concluded).

NOMENCLATURE: **14.5-mm Heavy Antiaircraft Machinegun Model ZPU-2** COUNTRY: **U.S.S.R.**

NATIVE DESIGNATION: 14.5 ММ ЗЕНИТНАЯ ПУЛЕМЕТНАЯ УСТАНОВКА ЗПУ-2 ADOPTED: 1955 ?

The Soviet 14.5-mm heavy antiaircraft machinegun Model ZPU-2 is the dual-gun version of the ZPU-4 (FOM-2-1005-4-14.5-2). It differs from the ZPU-4 in the number of guns involved and in the types of mounts used.

There are three different types of mounts for the dual gun: (1) a two-wheeled carriage, (2) a vehicular mount, and (3) a naval mount.

The two-wheeled carriage is essentially a single-axled version of the ZPU-4 mount. Although the carriage is sturdily built for cross-country towing, in order to avoid excessive dispersion the guns should not be fired until the jacks have been lowered.

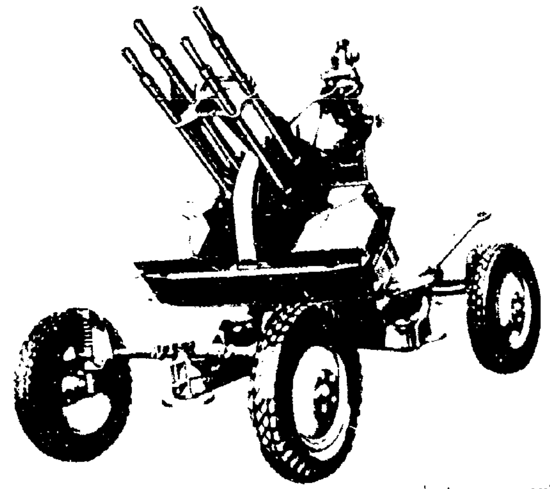
The dual vehicular mount is used on the BTR-152 and BTR-40 armored personnel carriers (FOM-2-2352-1-2 and FOM-2-2352-1-4). The BTR-50P amphibious armored personnel carrier (FOM-2-2354-3-1), although not definitely known to carry it, has ample space and structural strength to do so.

CURRENT STATUS:	Ltd standard
USING COUNTRIES:	U.S.S.R. and all Bloc countries, and Egypt, Laos
WEAPON:	
Caliber	14.5 mm
Operation-type	Recoil
Fire-type	Automatic
Cyclic rate	600 rpm per gun
Length overall	79 in.
Weight unloaded	108 lb
Aprx. muzzle velocity	3281 fps
Aprx. max. hor. range	7000 m
FEED:	
Type	Metallic link belt
Location	Either side of receiver
Capacity	150 rd per gun
BARREL:	
Cooling	Air
Length	53 in.
Barrel change	Yes
SIGHTS:	
Front-type	Does not apply
Rear-type	Does not apply
Optical sight-type	Reflex
-power	?
ACTION:	
Locking feature-type	Rotating bolt head
MOUNT:	
Type	See text
Weight	838 lb w/guns

Figure 181. 14.5-MM Heavy Antiaircraft Machinegun Model ZPU-2.

NOMENCLATURE: 14.5-mm Heavy Antiaircraft Machinegun Model ZPU-4 COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 14,5 ММ ЗЕНИТНАЯ ПУЛЕМЕТНАЯ УСТАНОВКА ЗПУ-4 ADOPTED: 1955 ?



The Soviet 14.5-mm heavy antiaircraft machinegun Model ZPU-4 is, properly speaking, an assembly consisting of four Model KPV machineguns mounted on a four-wheeled carriage. The symbol "ZPU" stands for "antiaircraft machinegun installation."

Although conceived during World War II as an antiaircraft machinegun, its present usefulness in this role against modern high-performance aircraft is severely restricted by its manually operated elevation and traverse mechanisms, as well as by its small caliber. It is quite effective, however, against low and slow aircraft such as helicopters, and against ground targets of opportunity such as armored personnel carriers and trucks.

The basic part of this weapon system, the KPV machinegun, is a recoil-operated, air-cooled weapon which fires from the open-bolt position. The gun is fed by a flexible, metallic, link belt which consists of 10-round, nondisintegrating-link sections which may be coupled with other link sections. Locking of the action at the time of firing is accomplished by rotation of the bolt head. Barrels can be changed by replacing the entire barrel assembly consisting of barrel, connecting sleeve, barrel jacket, and flash hider. The practical rate of fire of the ZPU-4 is 150 rounds per gun per minute.

CURRENT STATUS:	Standard
USING COUNTRIES:	U.S.S.R., Bulgaria, East Germany, Cuba, Rumania, Poland, Communist China, North Korea, Egypt
WEAPON:	
Caliber	14.5 mm
Operation-type	Recoil
Fire-type	Automatic
Cyclic rate	600 rpm per gun
Length overall	79 in.
Weight unloaded	108 lb
Aprx. muzzle velocity	3281 fps
Aprx. max. hor. range	7000 m
FEED:	
Type	Metallic link belt
Location	Either side of receiver
Capacity	150 rd per gun
BARREL:	
Cooling	Air
Length	53 in.
Barrel change	Yes
SIGHTS:	
Front-type	Does not apply
Rear-type	Does not apply
Optical sight-type	Reflex
-power	?
ACTION:	
Locking feature-type	Roteting bolt head
MOUNT:	
Type	4-wheeled trailer
Weight	4400 lb w/guns

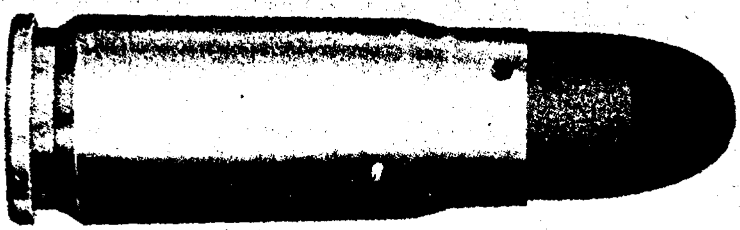
Figure 182. 14.5-MM Heavy Antiaircraft Machinegun Model ZPU-4.

NOMENCLATURE: 7.62-mm Tracer Cartridge Type PT

COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 7,62 ММ ПИСТОЛЕТНЫЙ ПАТРОН С ТРАССИРУЮЩЕЙ ПУЛЕЙ

ADOPTED: 1941



The Soviet 7.62-mm tracer cartridge Type PT consists of a brass case, a Berdan-type primer, a charge of single-base propellant stabilized with diphenylamine, and a bullet. The bullet consists of a gilding-metal-clad steel jacket, a lead point filler, and a gilding-metal-clad steel cup containing a quantity of tracer mix. The brass primer cup contains a mixture of mercury fulminate, potassium chlorate, and antimony sulfide. There is no waterproofing of the joint between the primer cup and the primer pocket, nor between the bullet and the case neck.

<u>CURRENT STATUS</u>: --------- Ltd standard <u>NATIVE USING WEAPONS</u>: --- PPSh and PPS submachineguns <u>COMPLETE ROUND</u>: Caliber ----------------- 7.62 x 25 Weight ------------------ 164 gr Length overall ---------- 1.36 in. Identifying markings ---- Green bullet tip <u>BULLET</u>: Weight ------------------ 84 gr Length ------------------ 0.65 in. Material ---------------- Gilding-metal-clad steel jacket, lead point filler, and gilding-metal-clad steel cup containing tracer mix.	<u>CASE</u>: Weight w/primer ------- 72 gr Length ---------------- 0.97 in. Max. body dia. -------- 0.386 in. Material -------------- Brass Rim-type -------------- Rimless -diameter ------------ 0.39 in. <u>PROPELLANT</u>: Type ------------------ Single base Weight ---------------- 8 gr Configuration --------- Tubular

Figure 183. 7.62-MM Tracer Cartridge Type PT.

NOMENCLATURE: **7.62-mm Cartridge M1943 with Ball Bullet Type PS** COUNTRY: **U.S.S.R.**

NATIVE DESIGNATION: 7.62 ММ ПАТРОН ОБР. 1943 Г. С ОБЫКНОВЕННОЙ ПУЛЕЙ (ПС) ADOPTED: 1943

The Soviet 7.62-mm M1943 ball, Type PS cartridge is standard in the Soviet and satellite armies. It is used in the AK assault rifle and the RPK light machineguns.

The complete cartridge consists of a rimless, gilding-metal-clad steel case with a percussion primer, and a bullet composed of a flat-nosed, mild-steel core enveloped by a lead sleeve. The bullet's jacket is constructed of gilding-metal-clad steel.

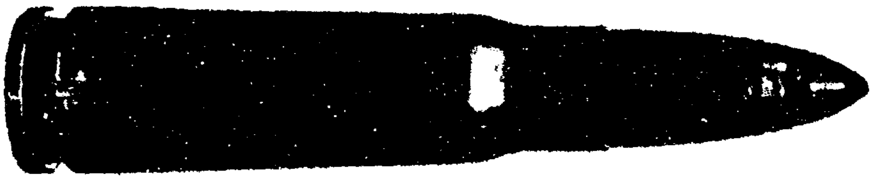
The Soviet Type-PS cartridge is much shorter and lighter than the standard 7.62-mm, M59, NATO cartridge.

<u>CURRENT STATUS</u>: ---------- Standard	<u>CASE</u>:
<u>USING COUNTRIES</u>: --------- U.S.S.R., Poland, East Germany, North Korea, Egypt, Albania, Communist China, Czechoslovakia, Rumania	Weight w/primer ---- 105.51 gr
	Length ------------- 1.52 in.
	Max. body dia. ----- 0.44 in.
	Material ----------- Gilding-metal-clad steel
	Rim-type ----------- Rimless
	-diameter --------- 0.44 in.
<u>NATIVE USING WEAPONS</u>: ---- AK assault rifle and RPK light machineguns	<u>PROPELLANT</u>:
	Type --------------- Single base nitrocellulose
	Weight ------------- 25.06 gr
	Configuration ------ Tubular
<u>COMPLETE ROUND</u>:	
Caliber ------------------ 7.62 mm	
Weight ------------------- 253.25 gr	
Length overall ----------- 2.18 in.	
Identifying markings ----- None	
<u>BULLET</u>:	
Weight ------------------- 122.68 gr	
Length ------------------- 1.05 in.	
Material ----------------- Gilding-metal-clad steel jacket, lead sleeve, mild-steel core	

Figure 184. 7.62-MM Ball Cartridge M1943 Type PS.

NOMENCLATURE: **7.62-mm API Cartridge M1943 Type BZ** COUNTRY: **U.S.S.R.**

NATIVE DESIGNATION: 7,62 ММ ПАТРОН ОБР. 1943 Г. С БРОНЕБОЙНО-ЗАЖИГАТЕЛЬНОЙ ПУЛЕЙ БЗ ADOPTED: 1943



The Soviet 7.62 mm armor-piercing, incendiary cartridge, M1943, Type BZ is fired in the AK assault rifle and the RPK light machineguns.

The cartridge has a gliding-metal-clad-steel, shouldered, rimless case with a corrosive percussion primer and an armor-piercing bullet. The bullet consists of a two-piece, gliding-metal-clad-steel jacket enveloping the armor-piercing, hardened-steel core, the tubular lead filler, and the incendiary charge located in its base.

The cartridge is identified by the red band on the black bullet tip. It is packed in the same type packing containers as described for the M1943 ball Type PS cartridge.

<u>CURRENT STATUS</u>: ---------- Standard

<u>USING COUNTRIES</u>: --------- U.S.S.R., Poland, East Germany, North Korea, Egypt, Albania, Communist China, Czechoslovakia, Rumania

<u>NATIVE USING WEAPONS</u>: ---- AK assault rifle and RPK light machineguns

<u>COMPLETE ROUND</u>:

Caliber ------------------	7.62 mm
Weight -------------------	248.22 gr
Length overall -----------	2.19 in.
Identifying markings -----	Black bullet tip w/red band

<u>BULLET</u>:

Weight -------------------	120.02 gr
Length -------------------	1.08 in.
Material -----------------	Gilding-metal-clad-steel jacket, steel core, lead sleeve, incendiary charge filler

<u>CASE</u>:

Weight w/primer -----	103.42 gr
Length --------------	1.52 in.
Max. body dia. ------	0.44 in.
Material ------------	Gilding-metal-clad steel
Rim-type ------------	Rimless
-diameter ----------	0.44 in.

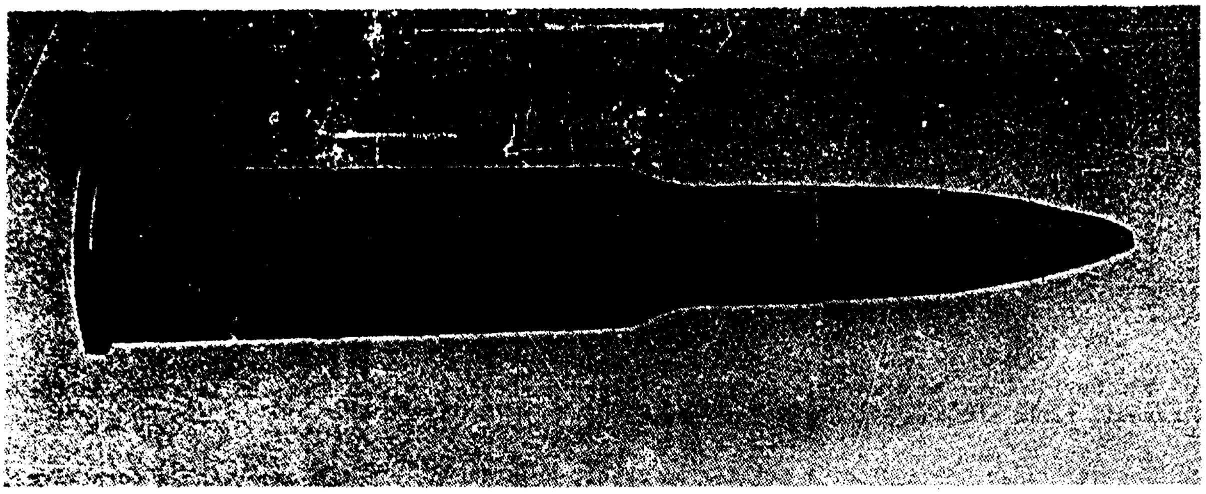
<u>PROPELLANT</u>:

Type ----------------	Single base nitrocellulose
Weight --------------	24.78 gr
Configuration -------	Tubular

Figure 185. 7.62-MM API Cartridge M1943 Type BZ.

NOMENCLATURE: 7.62-mm Ball Cartridge M1908 Type L **COUNTRY:** U.S.S.R.

NATIVE DESIGNATION: 7.62 ММ ПАТРОН С ЛЕГКОЙ ПУЛЕЙ ОБР. 1908 Г. Л **ADOPTED:** [illegible]



The Soviet 7.62-mm ball cartridge M1908 Type L is designed for use against personnel and light material targets. Its structure is conventional with the exception of a conical depression in the base of the bullet, enabling the bullet to expand and thus seal a worn barrel.

Before 1930, Type L bullets had cupronickel jackets. Since that time, however, jackets have been made of gilding-metal-clad steel. Cartridge cases are made either of brass or gilding-metal-clad steel, the latter type predominating.

Some M1908 cartridges, stamped with the Cyrillic letter "Ш" on the bases of the cartridge cases, were manufactured specifically for firing in the now-obsolete ShKAS aircraft machinegun. Cartridges bearing this mark can be fired in Goryunov machineguns (SG-43, SGM, SGM-T), but should not be fired in other automatic or semiautomatic weapons, as extraction difficulties, including broken extractors, will occur.

<u>CURRENT STATUS</u>: --------- Standard

<u>USING COUNTRIES</u>: -------- U.S.S.R. and most Bloc countries

<u>NATIVE USING WEAPONS</u>: --- RP-46, SG-43, SGM, and SGM-T machineguns

<u>COMPLETE ROUND</u>:
Caliber ----------------- 7.62 mm
Weight ------------------ 340 gr
Length overall ---------- 3.02 in.
Identifying markings ---- None

<u>BULLET</u>:
Weight ------------------ [illegible] gr
Length ------------------ 1.12 in.
Material ---------------- Gilding-metal-clad steel jacket, lead core

<u>CASE</u>:
Weight w/primer --- 140 gr
Length ------------ 2.11 in.
Max. body dia. ---- 0.48 in.
Material ---------- Gilding-metal-clad steel or brass
Rim-type ---------- Rimmed
-diameter -------- 0.57 in.

<u>PROPELLANT</u>:
Type -------------- Double base
Weight ------------ 51 gr
Configuration ----- Monoperforated tube

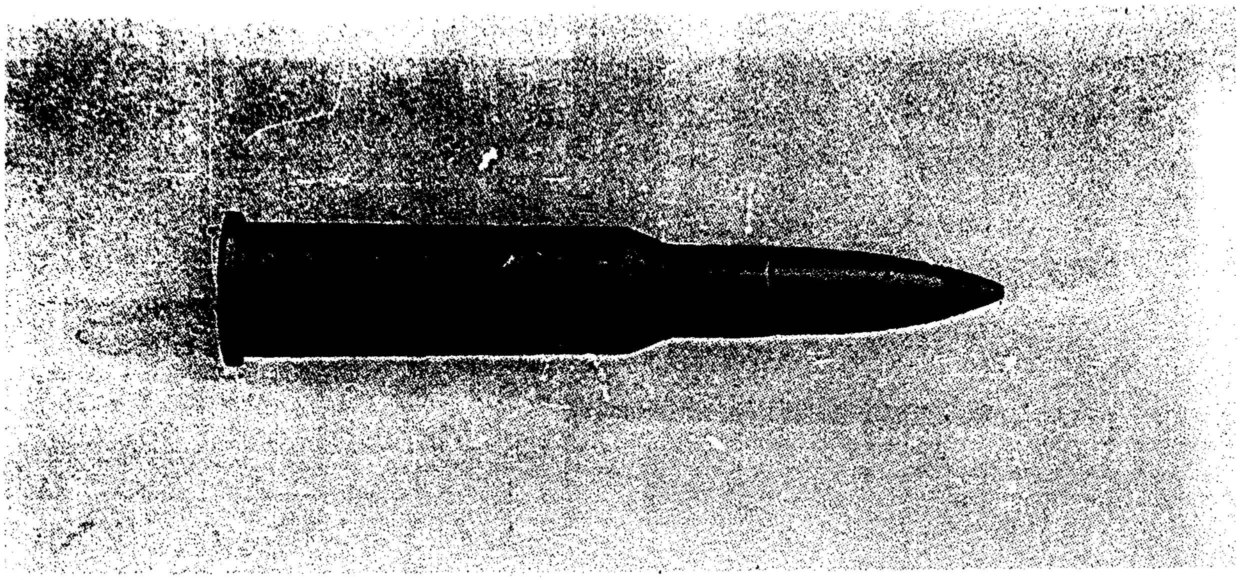
Figure 186. 7.62-MM Ball Cartridge M1908 Type L.

NOMENCLATURE: 7.62-mm Tracer Cartridge M1930 Type T

COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 7,62 ММ ПАТРОН С ТРАССИРУЮЩЕЙ ПУЛЕЙ ОБР. 1930 Г. Т

ADOPTED: 1930



The Soviet 7.62-mm tracer cartridge M1930 Type T consists of a cartridge case, a charge of single base (nitrocellulose) propellant, and a bullet. The case, made either of brass or of gilding-metal-clad steel, has a pocket in the base which contains a Berdan-type primer charged with a mixture of potassium chlorate, antimony sulfide, and mercury fulminate.

The bullet assembly consists of a gilding-metal-clad steel jacket containing a lead point filler and a quantity of tracer mix. The tip of the bullet jacket is colored green for identification.

These cartridges are packed 20 to a paper package, 22 packages (440 rounds) to a sealed, galvanized-metal container. Two containers are packed in a wooden box. The box is 19 inches long by 13.5 inches wide by 6 inches high, and has a gross weight of 57 pounds.

The muzzle velocity for Type T bullets ranges from 820 to 835 meters per second.

CURRENT STATUS: --------- Ltd standard

USING COUNTRIES: -------- U.S.S.R. and most Bloc countries

NATIVE USING WEAPONS: --- RP-46, SG-43, SGM, SGMB, SGMT, and PK machineguns

COMPLETE ROUND:
Caliber ----------------- 7.62 mm
Weight ------------------ 331 gr
Length overall ---------- 3.01 in.
Identifying markings ---- Green bullet tip

BULLET:
Weight ------------------ 144 gr
Length ------------------ 1.48 in.
Material ---------------- Gilding-metal-clad steel jacket, lead point filler, tracer mix

CASE:
Weight w/primer --- 141 gr
Length ------------ 2.11 in.
Max. body dia. ---- 0.48 in.
Material ---------- Gilding-metal-clad steel or brass
Rim-type ---------- Rimmed
-diameter -------- 0.57 in.

PROPELLANT:
Type -------------- Single base
Weight ------------ 46 gr
Configuration ----- Tubular

Figure 187. 7.62-MM Tracer Cartridge M1930 Type T.

NOMENCLATURE: 7.62-mm Armor-Piercing Cartridge Type B-30 — COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 7.62 ММ ПАТРОН С БРОНЕБОЙНОЙ ПУЛЕЙ ОБР. 1930 Г. Б-30 — ADOPTED: 1930

The Soviet 7.62 armor-piercing cartridge Type B-30, which can be identified by its black-tipped bullet, is used against personnel and lightly armored targets such as aircraft. The bullet is conventional, having a hardened steel core. The cartridge case can be either of brass or gilding-metal-clad steel.

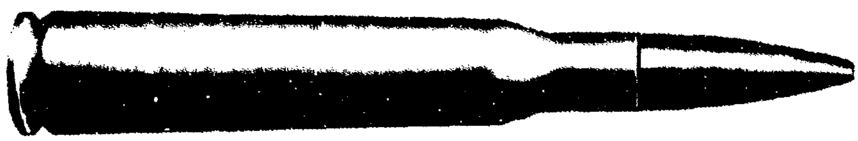
B-30 cartridges, manufactured for use in the now-obsolete ShKAS aircraft machinegun, are identified by the Cyrillic letter "Ш" stamped on the base of the case. Rounds so marked can be fired in the Goryunov machineguns (SG-43, SGM, SGM-T), but should not be fired in other automatic or semi-automatic weapons, as extraction difficulties, including broken extractors, will occur.

CURRENT STATUS: --------- Standard	CASE:
USING COUNTRIES: -------- U.S.S.R. and most Bloc countries	Weight w/primer --- 154 gr
NATIVE USING WEAPONS: --- RP-46, SG-43, SGM, and SGM-T machineguns	Length ------------ 2.11 in.
COMPLETE ROUND:	Max. body dia. ---- 0.48 in.
Caliber ---------------- 7.62 mm	Material ---------- Gilding-metal-clad steel or brass
Weight ------------------ 371 gr	Rim-type ---------- Rimmed
Length overall ---------- 3.01 in.	-diameter -------- 0.57 in.
Identifying markings ---- Black bullet tip	PROPELLANT:
BULLET:	Type -------------- Single base
Weight ------------------ 169 gr	Weight ------------ 48 gr
Length ------------------ 1.43 in.	Configuration ----- Monoperforated tube
Material ---------------- Gilding-metal-clad steel jacket, lead filler, hardened steel core	

Figure 188. 7.62-MM Armor-Piercing Cartridge Type B-30.

NOMENCLATURE: 12.7-mm Armor-Piercing Cartridge Type B-30 COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 12,7 ММ ПАТРОН С БРОНЕБОЙНОЙ ПУЛЕЙ ОБР. 1930 Г. Б-30 ADOPTED: 1930



The Soviet 12.7-mm armor-piercing cartridge Type B-30 is currently used in the DShK Model 38/46 heavy machinegun and the UB aircraft machinegun.

The bullet consists of a gilding-metal-clad steel jacket, a hardened steel core, and a lead filler. It is effective against lightly armored vehicles, machinegun nests, and aircraft.

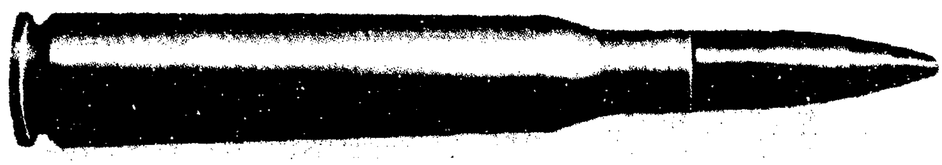
The cartridges, which can be identified by their black bullet tips, are packed in zinc boxes, 85 loose rounds to a box, with 2 boxes to a wooden case.

CURRENT STATUS:	Ltd standard
USING COUNTRIES:	U.S.S.R., all Bloc countries, Afghanistan ?
NATIVE USING WEAPONS:	DShK M38/46 and UB machineguns
COMPLETE ROUND:	
Caliber	12.7 mm
Weight	2062 gr
Length overall	5.76 in.
Identifying markings	Black bullet tip
BULLET:	
Weight	788 gr
Length	2.45 in.
Material	Gilding-metal-clad steel jacket, lead filler, hardened steel core
CASE:	
Weight w/primer	1003 gr
Length	4.25 in.
Max. body dia.	0.85 in.
Material	Brass
Rim-type	Rimless
-diameter	0.85 in.
PROPELLANT:	
Type	Single base
Weight	271 gr
Configuration	Multiperforated tube

Figure 189. 12.7-MM Armor-Piercing Cartridge Type B-30.

NOMENCLATURE: 12.7-mm API Cartridge Type B-32 COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 12,7 ММ ПАТРОН С БРОНЕБОЙНО-ЗАЖИГАТЕЛЬНОЙ ПУЛЕЙ УР. 1932 Г. Б-32 ADOPTED: 1932



The Soviet 12.7-mm API cartridge Type B-32 is currently used in the DShK Model 38/46 heavy machinegun and the UB aircraft machinegun. The cartridges can be identified by their black and red bullet tips.

The bullet consists of a gilding-metal-clad steel jacket, a hardened steel core, an incendiary mixture ahead of the core, and a lead filler. The cartridge was designed to penetrate lightly armored targets, and to ignite flammable material behind the armor.

The ammunition is packed in two ways: (1) 41 linked rounds in a wooden box, and (2) 85 loose rounds in a zinc box, with 2 boxes to a wooden case.

CURRENT STATUS: --------- Standard	CASE:
USING COUNTRIES: -------- U.S.S.R., all Bloc countries, Afghanistan ?	Weight w/primer --- 1038 gr
NATIVE USING WEAPONS: --- DShK M38/46 and UB machineguns	Length ------------ 4.24 in.
COMPLETE ROUND:	Max. body dia. ---- 0.85 in.
Caliber ----------------- 12.7 mm	Material ---------- Brass
Weight ------------------ 2025 gr	Rim-type ---------- Rimless
Length overall ---------- 5.78 in.	-diameter -------- 0.85 in.
Identifying markings ---- Black and red bullet tip	PROPELLANT:
BULLET:	Type -------------- Single base
Weight ------------------ 736 gr	Weight ------------ 251 gr
Length ------------------ 2.5 in.	Configuration ----- Multiperforated tube
Material ---------------- Gilding-metal-clad steel jacket, lead filler, hardened steel core, incendiary mixture	

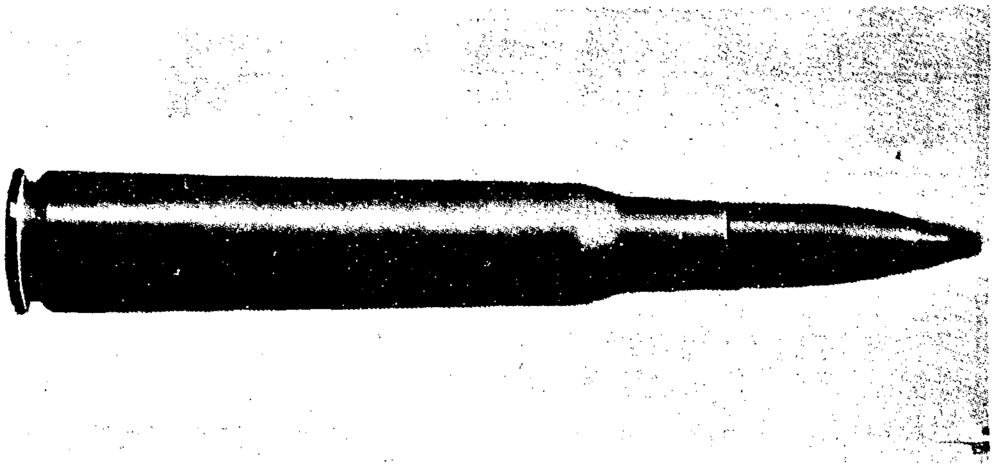
Figure 190. 12.7-MM API Cartridge Type B-32.

NOMENCLATURE: 12.7-mm API Tracer Cartridge Type BZT

COUNTRY: U.S.S.R.

NATIVE DESIGNATION: 12,7 ММ ПАТРОН С БРОНЕБОЙНО-ЗАЖИГАТЕЛЬНО-ТРАССИРУЮЩЕЙ ПУЛЕЙ БЗТ

ADOPTED: 1942 ?



The Soviet 12.7-mm API-T cartridge Type BZT is currently used in the DShK Model 38/46 heavy machinegun and the UB aircraft machinegun. The cartridges can be identified by their purple and red bullet tips.

The bullet consists of a gilding-metal-clad steel jacket, a steel armor-piercing core, an incendiary composition ahead of the core, and a tracer element housed in a steel capsule behind the core. The tracer burns out after approximately 2600 yards of flight.

Since the BZT bullet has considerably less penetration and incendiary effect than have the armor-piercing and armor-piercing incendiary bullets, its principal use is for fire correction.

The ammunition is packed in two ways: (1) 41 linked rounds in a wooden box, and (2) 85 loose rounds in a zinc box, with 2 boxes to a wooden case.

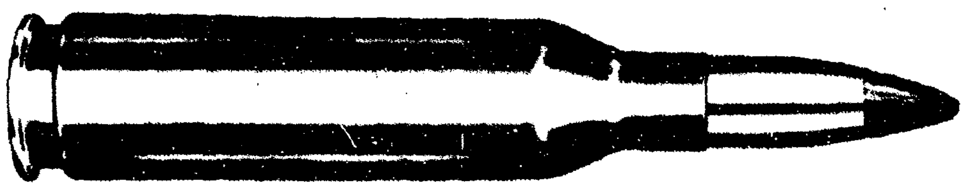
CURRENT STATUS: --------- Standard	
USING COUNTRIES: -------- U.S.S.R., all Bloc countries, Afghanistan ?	
NATIVE USING WEAPONS:--- DShK M38/46 and UB machineguns	
COMPLETE ROUND:	
Caliber ---------------- 12.7 mm	
Weight ----------------- 1984 gr	
Length overall --------- 5.78 in.	
Identifying markings --- Purple and red bullet tip	
BULLET:	
Weight ----------------- 681 gr	
Length ----------------- 2.51 in.	
Material --------------- Gilding-metal-clad steel jacket, steel core, tracer, incendiary composition	
	CASE:
	Weight w/primer --- 1049 gr
	Length ------------ 4.24 in.
	Max. body dia. ---- 0.85 in.
	Material ---------- Brass
	Rim-type ---------- Rimless
	-diameter -------- 0.85 in.
	PROPELLANT:
	Type -------------- Single base
	Weight ------------ 254 gr
	Configuration ----- Multiperforated tube

Figure 191. 12.7-MM API Tracer Cartridge Type BZT.

NOMENCLATURE: **14.5-mm API Cartridge Type BS-41** COUNTRY: **U.S.S.R.**

NATIVE DESIGNATION: 14,5 MM ПАТРОН ОБР. 1941 Г.
С БРОНЕБОЙНО-ЗАЖИГАТЕЛЬНОЙ ПУЛЕЙ
(СО СПЕЦИАЛЬНЫМ СЕРДЕЧНИКОМ) БС-41

ADOPTED: 1941



The Type BS-41 cartridge is used in the Soviet 14.5-mm machinegun fitted to the ZPU-1, ZPU-2, and ZPU-4 antiaircraft weapons. Similar rounds were used in the obsolete, shoulder-fired, antitank rifles PTRS-1941 (Simonov) and PTRD-1941 (Degtyarev).

The complete round has a steel-jacketed bullet with a tungsten-carbide core and a brass case. The incendiary composition is located in the nose of the bullet's jacket, forward of the core.

The round is identified by the red bullet with a black tip. They are packed in sealed, galvanized, metal containers, 42 to a container, with two containers to a wooden box.

The 14.5-mm cartridge can be used against armored vehicles and low-flying aircraft. The projectile has a high velocity and good penetration capabilities.

CURRENT STATUS: ---------- Standard

USING COUNTRIES: --------- U.S.S.R.

NATIVE USING WEAPONS: ---- ZPU-1, ZPU-2, and ZPU-4 antiaircraft weapons

COMPLETE ROUND:
Caliber ------------------ 14.5 mm
Weight ------------------- 3107.66 gr
Length overall ----------- 6.11 in.
Identifying markings ----- Red bullet with black tip

BULLET:
Weight ------------------- 984.62 gr
Length ------------------- 2 in.
Material ----------------- Steel jacket, tungsten-carbide core, incendiary filler

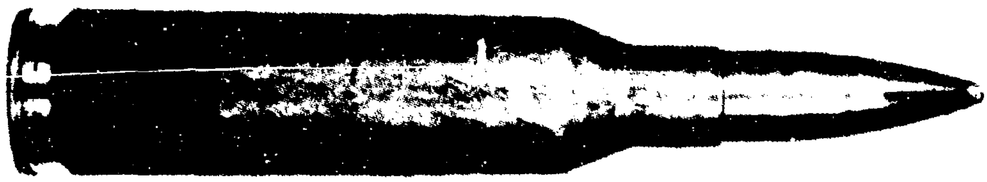
CASE:
Weight w/primer ---- 1682.72 gr
Length ------------- 4.48 in.
Max. body dia. ----- 1.06 in.
Material ----------- Brass
Rim-type ----------- Rimless
-diameter --------- 1.07 in.

PROPELLANT:
Type --------------- Single-base nitrocellulose
Weight ------------- 440.32 gr
Configuration ------ Multiperforated tube

Figure 192. 14.5-MM API Cartridge Type BS-41.

NOMENCLATURE: **14.5-mm API Cartridge Type B-32** COUNTRY: **U.S.S.R.**

NATIVE DESIGNATION: 14,5 ММ ПАТРОН ОБР. 1932 Г.
С БРОНЕБОЙНО-ЗАЖИГАТЕЛЬНОЙ ПУЛЕЙ Б-32 ADOPTED: 1932



The Type B-32 cartridge was designed for use in the Soviet 14.5-mm antitank rifles PTRS-1941 (Simonov) and PTRD-1941 (Degtyarev) which during World War II were employed extensively by the Soviet Army against lightly armored vehicles, as well as against light and medium tanks. It was designed to combat these vehicles and tanks within a range of 500 meters, and to ignite inflammable material (gasoline) behind the armor.

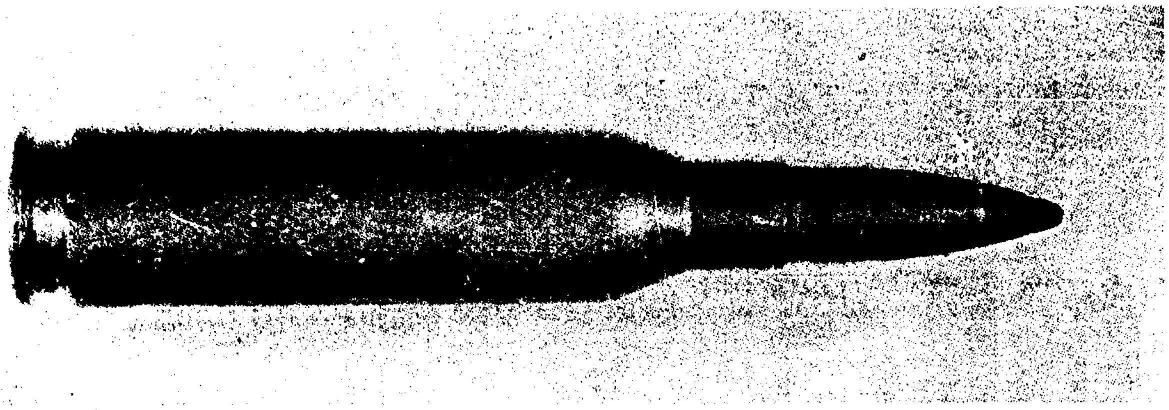
Since World War II the Soviets have adopted the 14.5-mm ZPU-series of machinegun weapons, and have furnished such weapons to the Satellite armies. All available evidence indicates that this same cartridge is used in the ZPU-1, ZPU-2, and ZPU-4 weapons, as is also the similar, newer cartridge.

CURRENT STATUS: ---------- Standard USING COUNTRIES: --------- U.S.S.R. NATIVE USING WEAPONS: ---- ZPU-1, ZPU-2, and ZPU-4 antiaircraft weapons COMPLETE ROUND: Caliber ------------------ 14.5 mm Weight ------------------- 3357.1 gr Length overall ----------- 6.13 in. Identifying markings ----- Black bullet tip with red band adjacent BULLET: Weight ------------------- 989.84 gr Length ------------------- 2.61 in. Material ----------------- Steel jacket, steel core, incendiary filler	CASE: Weight w/primer ---- 1949.9 gr Length ------------- 4.48 in. Max. body dia. ----- 1.06 in. Material ----------- Brass Rim-type ----------- Rimless -diameter --------- 1.07 in. PROPELLANT: Type --------------- Single base nitrocellulose Weight ------------- 417.36 gr Configuration ------ Multiperforated tube

Figure 193. 14.5-MM API Cartridge Type B-32.

NOMENCLATURE: **14.5-mm API-T Cartridge Type BZT** COUNTRY: **U.S.S.R.**

NATIVE DESIGNATION: ? ADOPTED: 1955 ?



The Soviet 14.5-mm armor-piercing, incendiary tracer cartridge Type BZT consists of a brass cartridge case, a Berdan-type primer, a charge of single-base propellant, and a bullet. The bullet consists of: a brass-clad steel jacket, which houses a charge of incendiary mixture composed of barium nitrate, aluminum, and magnesium; a hardened steel core; and a gilding-metal-clad steel cup containing tracer mix. A lead sheath surrounds the rear half of the core and the entire length of the tracer cup.

Although the tabulated data refer to brass-cased BZT cartridges, the cartridges have also been manufactured with steel cases. The steel-cased cartridges are about 100 grains lighter than the brass-cased ones, a difference due solely to the weight difference of their respective cartridge cases.

When fired in the ZPU series of antiaircraft weapons, the muzzle velocity of the projectiles is 1000 meters per second; tracer burnout occurs approximately 1900 meters from the gun muzzle.

CURRENT STATUS: --------- Standard

NATIVE USING WEAPONS: --- ZPU-1, ZPU-2, and ZPU-4 antiaircraft weapons

COMPLETE ROUND:
Caliber ---------------- 14.5 x 114
Weight ----------------- 3016 gr
Length overall ---------- 6.12 in.
Identifying markings ---- Purple and red bullet tip

BULLET:
Weight ----------------- 919 gr
Length ----------------- 2.68 in.
Material ---------------- Brass-clad steel jacket containing incendiary mixture, a hardened steel core, a lead sleeve, and a gilding-metal-clad steel cup containing tracer mix.

CASE:
Weight w/primer --- 1615 gr
Length ------------ 4.48 in.
Max. body dia. ---- 1.057 in.
Material ---------- Brass
Rim-type ---------- Rimless
-diameter --------- 1.059 in.

PROPELLANT:
Type -------------- Single base
Weight ------------ 482 gr
Configuration ----- Multiperforated cylinder

Figure 194. 14.5-MM API-T Cartridge Type BZT.

APPENDIX II

ARMOR MATERIALS DATA

2.1 INTRODUCTION

This appendix contains additional unclassified information on armor materials, supplementing the basic information contained in Section 3.10.3. Classified data on armor materials is also contained in Volume II (USAAMRDL Technical Report 71-41B) and are referenced where appropriate in this section.

2.2 ARMOR MATERIAL CHARACTERISTICS

2.2.1 ARMOR TYPES

There are three different types of armor materials/systems covered in this section. The basic materials or systems are broken down as follows:

- Specification armor
- Experimental armor
- Spaced armor

2.2.1.1 Specification Armor: This section includes information on solid armors of the type which bear some degree of specification-approved ballistic data. Within these limitations, the section includes information for various armor materials and armor systems and for both homogenous and nonhomogeneous materials. Pertinent information on these general categories of armor and for specific armors within each category make up the remainder of this section. General arrangement of the data is based upon a breakdown between homogeneous and nonhomogeneous armors. Reference to the appropriate material specification is suggested if more detailed data regarding any material is needed.

2.2.1.2 Homogeneous Types of Solid Armor: This category presently includes certain steel and lightweight metal armors. Each of these are discussed separately in paragraphs that follow.

Additional types of homogeneous armor for which no degree of specification approval presently exists are discussed, as applicable, in paragraph 2.2.2.

2.2.1.3 Homogeneous Steel Armor: Specification-type solid-steel armors of a homogeneous nature represent a segment of the armor spectrum which was one of the earliest explored and developed. Included in this category are, primarily, steel armor materials which defeat attack by the absorption of energy. These armors exhibit a full multihit capability.

Steels which defeat ballistic attack by energy absorption rely upon their strength. This strength results from a combination of high hardness and high ductility.

Projectile size as related to armor thickness is also related to hardness and penetration resistance. When projectiles undermatch the armor (the diameter is less than the plate thickness), penetration resistance increases with hardness until excessive brittleness occurs. Then the penetration resistance decreases, often accompanied by spalling. As the projectile becomes more overmatching, the optimum hardness is reduced.

In addition to providing reasonably good ballistic protection against a considerable range of projectile threat conditions, homogeneous steel armors possess certain inherent advantages because of their nonballistic properties. These properties include low cost, ready availability, comparative ease of fabrication, and structural (load-carrying) capability. A major disadvantage for some aircraft applications is the material weight for a given protection level.

Excluded from coverage in this document are three specification-type steels of a homogeneous nature. Two of these materials are rolled homogeneous steel conforming to Specification MIL-A-256 and nonmagnetic rolled steel conforming to Specification MIL-A-434. These older materials are no longer of much practical interest for purposes of armor design. For anyone interested, however, the specifications do include information regarding ballistic performance of the respective materials against caliber .30 AP M2 and caliber .50 AP M2 projectiles at 0 degree obliquity. The third material, cast steel armor in accordance with Specification MIL-S-11356 (Ord), is excluded because very little cast steel is produced in their gages. Another material, face-hardened steel in accordance with Specification JAN-A-784, is discussed later with the nonhomogeneous materials because it is not truly homogeneous in all respects, because of the face-hardening process involved.

2.2.1.3.1 Wrought Homogeneous Steel, MIL-S-12560B (Ord): Steel produced in accordance with this specification is made in two classes. Class 1, the one of prime interest as an armor steel, is heat treated to produce maximum penetration resistance. Class 2 is heat treated to produce maximum resistance to shock.

Class 1 steel is rolled (or wrought) homogeneous steel armor mentioned earlier in this section as one of the standards against which new armors have been compared ballistically for a number of years. Because of its use as a standard for comparison, this steel was assigned a velocity merit rating of 1.00 (weight merit rating of 100). This material is a low-alloy rolled steel, hardened to the range of 330 to 400 Brinell, depending on plate thickness (up to 1 inch). The material depends on its strength to stop projectiles. Several compositions of high-quality, low-alloy steel meet the specification requirements. This steel is readily available in nominal thicknesses from 1/4 inch to 6 inches at moderate cost, but it is heavier, for equivalent protection, than some of the more recently developed steels. Table XXIX shows the Brinell hardness requirements for specific nominal thicknesses of Class 1 and 2 plate.

2.2.1.3.2 Nonmagnetic Rolled Steel, MIL-A-13259B (MR): This material, more commonly referred to as Hadfield-manganese steel, serves as the standard of comparison for performance of armor against fragment-simulating projectiles, caliber .30 (44 grain) and smaller. Against these projectiles, this material would have a velocity merit rating of 1.00, or a weight merit rating of 100. (In terms of its ballistic performance against other projectiles, this material is compared with MIL-S-12500 (Ord) steel, as is true of other armors.)

This homogeneous steel is austenitic in microstructure, and in its final form has high toughness, strength, and ductility. Its nonmagnetic characteristics provide special advantages for use in sensitive areas where magnetic materials might interfere with operation of instruments or other equipment.

2.2.1.3.3 Wrought High-Hardness Steel, MIL-S-46100 (MR): This is a comparatively new rolled homogeneous steel armor in terms of specification approval. It is a low-alloy steel plate and is low in cost. This steel was developed as part of the effort to produce high-hardness steels capable of shattering projectiles on impact. The material is uniformly hardened to an average Brinell hardness of 485 to 530. Chemical composition is somewhat dependent upon individual suppliers.

TABLE XXIX. BRINELL HARDNESS REQUIREMENTS FOR MIL-S-12560B (ORD) STEEL PLATE			
Specified Nominal Thickness of Plate (in.)	Armor Class	Brinell Hardness Range (3,000 kg load)	Brinell Indentation Diameters (mm)
1/4 to less than 1/2	1	341 - 388	3.30 - 3.10
1/2 to less than 3/4	1	331 - 375	3.35 - 3.15
3/4 to less than 1-1/4	1	321 - 375	3.40 - 3.15
1-1/4 to less than 2	1	293 - 331	3.55 - 3.35
2 to less than 4	1	269 - 311	3.70 - 3.45
4 to 6 incl	1	241 - 277	3.90 - 3.65
7/8 to 1-1/4 incl	2	277 - 321	3.65 - 3.40

2.2.1.4 Homogeneous Light Metal Armors: Certain light metal armors make up a second general group of materials falling into the classification of specification-type, homogeneous solid armors. This general category includes armor fabricated from various aluminum and titanium alloys. A number of additional experimental armors of this type are discussed in paragraph 2.2.2.

In all cases, these light metal armor materials provide ballistic protection by absorption of energy from the impacting projectile. Surface hardnesses are not great enough to shatter the projectile.

Types of aluminum alloy armor have been used for many years. In general, the ballistic capabilities of the light metals are good, especially at obliquities, when compared with homogeneous steel armors of the same areal density. All such armors possess full multihit capabilities.

Light metal armors have an additional advantage, as do the steels, because of their structural capabilities, relative ease of fabrication, comparatively low cost in some cases, and, in most cases, ready availability. In

many cases though thicker for the same protection level, these metals may still prove to be lighter than steel. Especially in the case of aluminum, the rigidity due to increased thickness may often reduce or eliminate the need for added stiffeners.

Excluded from coverage are three specification-type homogeneous light metal armors which are of little current interest for purposes of armor design. This category includes an aluminum (2024-T4) alloy armor conforming to Specification MIL-A-7169, a titanium alloy (Ti-3Mn-Complex) armor conforming to Specification MIL-A-25536 (Wep), and a magnesium alloy (13Li-6Al) armor conforming to Specification MIL-A-2164 (Aer). Information regarding ballistic performance and other properties of these materials can be obtained from the specifications.

2.2.1.4.1 Weldable Aluminum Alloy Armor, MIL-A-46027C(MR): Material complying with this specification includes weldable, strain-hardened, wrought aluminum alloy armor plate of the basic 5083 and 5456 types. The material is available in nominal thicknesses from 3/4 inch to 3 inches, inclusive. This alloy has excellent ductility and toughness and is very resistant to cracking under shock. Its weldability permits an extended range of possible use, especially from a structural standpoint.

In general, this armor material is especially worthy of consideration as protection against fragments, but also has definite capabilities against small-arms ammunition.

2.2.1.4.2 Heat-Treatable, Weldable Aluminum Alloy Armor, MIL-A-46063B (MR): This is one of the more recent specification-approved types of aluminum alloy armor material. It is a heat-treatable, weldable wrought alloy of the 7039-T6 type. Aluminum, zinc, and magnesium are the major elements in its composition. The material is produced in nominal thicknesses from 3/4 inch to 4 inches, inclusive. An inherent tendency to corrode under stress is minimized by specification-required testing, but is pertinent for design consideration where applicable.

Probably because of its higher strength, the penetration resistance of this alloy tends to be generally better than that of the other aluminum alloy discussed in paragraph 2.2.1.4.1. Its ductility is considerably lower, however, and spalling occurs under some attack conditions, especially in the case of fragments.

2.2.1.4.3 Weldable Titanium Alloy Armor, MIL-T-46077 (MR): Although now one of the most widely used titanium alloys, this material is relatively new as a specification-approved armor material. This specification covers a weldable, wrought titanium alloy armor plate in the mill annealed condition and of the 6Al-4V class in its composition. This extra-low interstitial element (ELI) grade material has a lower oxygen, carbon, and nitrogen content than the basic 6Al-4V commercial class titanium, with correspondingly improved ballistic performance characteristics. The material does, however, exhibit some tendency to spall against fragment simulators and ball ammunition. While this material is a good prospect for consideration under certain attack conditions, cost is sometimes a limiting factor in its use. Nominal thicknesses range from 1/4 inch to 2-1/4 inches.

2.2.1.5 Homogeneous Nonmetallic Armors: In its overall scope, this class of solid armor covers a number of basic types of material. Included are certain organic, transparent, and, theoretically, ceramic armors. In actuality, however, no armor material of the specification-approved type is presently available in this category. Armor fabricated from unbonded nylon fabric purchased to Specification MIL-C-12369 represents the closest approach to an armor of this type.

2.2.1.6 Nonhomogeneous Types of Solid Armor: This includes coverage of those specification types of solid armor that are nonhomogeneous in nature. This category presently includes limited numbers of armor falling into the nonhomogeneous steel, ceramic-organic composite, and transparent armor classifications. These classifications and specific armors in each class are discussed separately in the following paragraphs.

2.2.1.7 Nonhomogeneous Steel Armors: As discussed earlier in Section 3.10.3, projectile shattering supplemented by energy absorption represents one of the major mechanisms used to defeat ballistic attacks. Attainment of both of these capabilities in a truly homogeneous material is almost impossible. In view of this fact, nonhomogeneous armor has provided the alternate route toward this goal. In the case of steel, two separate armors of basically different natures represent specification-approved solutions to the problem. These armors, face-hardened and roll-bonded dual hardness steels, are discussed separately in the following paragraphs.

2.2.1.7.1 Face-Hardened Steel Armor, JAN-A-784: Armor of this type resists penetration primarily through deformation and breakup of the projectile. This armor is essentially homogeneous in nature, except that it has a hardened face supported by a softer, more ductile backup region. This hardness variation is produced by a greater carbon content near the

surface and a reduced amount of carbon in the rest of the plate, with suitable heat treatment. Armor of this type may be produced by carburizing.

In addition to its special ballistic capabilities, face-hardened steel armor possesses the many structural, manufacturing, and logistic advantages of most steel armors.

2.2.1.7.2 Roll-Bonded, Dual-Hardness Steel, MIL-S-46099 (MR) 2nd: This steel accomplishes essentially the same basic purposes as face-hardened steel, but in a different way and more effectively. Actually, roll-bonded, dual-hardness steel is the most effective lightweight steel armor developed to date, excelling all of the nonferrous and some of the composite armor arrays.

This armor is made essentially by roll-bonding a hard steel facing onto a softer steel backing and then rolling the composite to the desired thickness. The steel face develops a hardness of 62 Rockwell C (maximum) and, consequently, shatters AP projectiles. The tough steel backing, at 53 Rockwell C hardness (maximum), restrains the hard-faced plate laterally and stops projectile fragments.

2.2.1.7.3 Composite Armor: Composite armor is an armor system consisting of two or more different armor materials bonded together to form a protective unit. As indicated earlier in this section, a single composite armor of the ceramic-organic type represents the only one of this category currently backed by specification approval. The armor involved is a ceramic-faced composite lightweight armor to Specification MIL-A-46103 (MR). The specification is general in the sense that typical rather than exact material combinations are defined.

Armor of this type is designed to defeat ballistic attack by projectile shatter with subsequent energy absorption by backup material. Essentially, the armor consists of ceramic frontal plates bonded to nonmetallic or metallic backing materials. In all cases, a spall shield is applied over the ceramic armor material to minimize secondary fragments from spalls which might be created at projectile impact with the armor.

While providing a high degree of ballistic protection at lightweight against small-arms fire, a limited multihit capability restricts its use in applications where the possibility of numerous hits in a small area is

great. Structural and manufacturing capabilities also are less extensive than for the various types of metallic armor materials. Cost, though higher than for the homogeneous materials, is moderate, in comparison with some of the more advanced armors.

2.2.1.8 <u>Transparent Armors</u>: Although much work has been done in the area of transparent armors, and a number of such materials have been used, only two types currently bear specification approval. One of these types is bullet-resistant glass conforming to Specification MIL-G-5485. The other type is a laminated composite to Specification MIL-A-46108 (MR).

2.2.1.8.1 Bullet-Resistant, Flat, Laminated Glass, MIL-G-5485: This specification covers a bullet-resistant glass suitable for use in aircraft windshields and similar applications. The material is made in two types, regular and precision ground, and each type comes in two grades, general purpose and special purpose (high light transmission), depending upon the intended use. This glass consists of two or more plies of glass held together by a transparent interlayer.

No ballistic performance curves are available for this material. The specification, however, indicates that at an impact velocity of 2,700 (±40) fps, areal densities required to defeat caliber .30 and .50 AP M2 projectiles at various obliquities are as follows:

- Caliber .30 AP M2 projectiles

  0° obliquity - 30 psf

  30° obliquity - 24 psf

  60° obliquity - 17 psf

- Caliber .50 AP M projectiles

  42-1/2° obliquity - 40 psf (limit of lightweight armor)

  60° obliquity - 32 psf

NOTE: Refer to specification for more detailed information regarding exact nature of ballistic test procedures used to obtain these values.

2.2.1.8.2 Laminated Glass-Faced Composite Transparent Armor, Specification MIL-A-46108 (MR): This specification covers multilayer, glass-faced transparent composite armor containing a nonspalling plastic backing material. Such materials are produced in weights up to 16 psf and thicknesses up to 2-1/4 inches. In general, such armors will include a glass front plate, an interlayer material, and the plastic backing. The composite material will have a high degree of light transmittance, with minimum optical deviation and distortion.

2.2.2 EXPERIMENTAL ARMOR

In most cases, experimental types of solid armors exist (or may later exist) in the same general categories as the specification-type armors. In a general sense, the properties and attack-defeating mechanisms of these experimental armors are similar (sometimes identical) to specification-type armors in these same categories. Nonballistic (physical) properties for specification-type materials are usually well defined by the specification, and materials could be ordered on that basis alone, as far as these nonballistic properties are concerned. In the case of experimental materials, on the other hand, confirmation of material properties by the supplier would normally be a requirement.

All ballistic property data, other than that presented in a material specification, must be considered experimental and subject to confirmation before use. Sometimes even the specification-approved ballistic data is of a type not directly usable in design planning.

2.2.2.1 Homogeneous Types of Solid Armor: A considerable amount of experimental and developmental work has been accomplished or is under way on various types of homogeneous solid armor. Included in this category are armors of steel, light metal alloy, organic, and transparent types. Each of these general armor types and any pertinent specific armors of each type are discussed separately in subsequent paragraphs.

2.2.2.2 Homogeneous Steel Armors: Although steels represent the oldest class of armor material, some further experimental work is being accomplished in this area, and a number of experimental steel armors currently exist. One of the more significant of these nonspecification-type steel armors for current consideration is discussed in the following paragraph.

2.2.2.2.1 Rolled (300 Bhn) Steel: This rolled homogeneous steel armor is similar in many of its basic properties to the standard rolled homogeneous steel, Specification MIL-S-12560 (Ord), discussed in paragraph 2.2.1.3.1 . Use of this steel in armor applications has been limited primarily to defense against fragments.

2.2.2.3 Light Metal Homogeneous Armors: Experimental types of homogeneous solid armor exist in several light metal categories. These include various alloys of aluminum, titanium, and magnesium. Any significant specific examples of armors of current interest in these categories follow.

2.2.2.3.1 Aluminum Alloy Armors: There are currently no new developments in the area of experimental aluminum alloy armors which warrant serious consideration for armor design purposes because of their superior ballistic protection capabilities. Aluminum alloys of the 7076-T6 and 5086 varieties are commercially available and have recieved some consideration as armor materials. While only limited ballistic performance data are available for the 7075 material and none at all for the 5086 material, it is probable that their ballistic properties would not differ significantly from other aluminum alloy armors of the specification type.

2.2.2.4 Titanium Alloy Armors: A multitude of commercial and semicommercial types of titanium alloys have been evaluated for ballistic performance capabilities, but very few have ballistic properties warranting any consideration as prospective experimental armor candidates. One of these alloys is discussed briefly in the following paragraph.

2.2.2.4.1 Titanium Alloy, Ti-6Al-4V: This prospective armor, which is basically similar to the specification-type titanium alloy armor listed under Specification MIL-T-46077 (MR) in paragraph 2.2.1.4.3, represents an earlier commercial grade of the specification-type material. While many basic properties of the two materials are comparable, the specification material is somewhat superior ballistically.

2.2.2.4.2 Magnesium Alloy Armors: No experimental types of magnesium alloy armor warrant serious consideration for design purposes at the present time.

2.2.2.5 Homogeneous Nonmetallic Armors: Armors of this type include those of an organic or transparent nature. Under the category of homogeneous organic armor, only one opaque type, ballistic nylon, is discussed. Similarly, two types of transparent armor, Plexiglas and Lexan, are also discussed. Other armors of a similar nature are discussed separately under the nonhomogeneous portion of this section.

2.2.2.5.1 Nylon Armor: Nylon, in both bonded and unbonded forms, offers ballistic protection primarily against certain shell fragments. Its field of use may include incorporation in composite armors, and it may sometimes be added as backing material to upgrade the ballistic protection capability of existing armors. Such data for composite armors using nylon will be included, if pertinent, with the particular composites.

2.2.2.5.2 Plexiglas: Plexiglas is a monolithic, clear, totally organic material of the acrylic plastic type. The material, which is commercially available, offers some limited ballistic protection, especially against small caliber ball-type ammunition at the lower impact velocities. In general, the bonded Plexiglas laminates, discussed later under the nonhomogeneous transparent armors, offer greater protection than this solid material or the unbonded laminates.

2.2.2.5.3 Lexan*: Lexan is a transparent polycarbonate resin material that has high impact strength and dimensional stability characteristics. It has limited ballistic protection similar to Plexiglas, with greater resistance to crack propagation and shattering - desirable qualities for aircrew station transparencies.

2.2.2.6 Nonhomogeneous Types of Solid Armor: This covers experimental types of solid armor that are nonhomogeneous in nature and are of interest for purposes of current design consideration. This category includes, in general, nonhomogeneous steel armors (opaque), organic armors, many types of composite armors, and a number of transparent armors. Each of these general categories and specific armors of interest in each category are discussed in the following paragraphs.

2.2.2.7 Steel Armor, 5M21, Carburized and Ausformed: Steel armor of this type, produced by a combined carburizing-ausforming process, has a high-carbon, high-hardness surface which has a capability for projectile shatter, in some cases, and a high-toughness back. The resulting material represents an advance over earlier types of carburized armor plate that were not ausformed. This type of steel is commercially available, but at a relatively higher cost because of the extra processing involved.

2.2.2.8 Dual-Property Steel Armor, MIL-S-46099 (MR) 2nd: In addition to the specification-type dual-property steel armor discussed, other armors of similar makeup have been ivestigated. These armors will exhibit similar ballistic protection capabilities, with differences existing primarily in

*G. E. trademark

fabrication techniques and in certain resulting nonballistic properties (e.g., formability). Work to date has been based largely upon a 50-50 ratio between front and back plate thickness, which seems to be the optimum arrangement. In general, the range of front and back plate hardnesses used is as stated for the specification material.

2.2.2.9 Doron Organic Armor: Doron is a basic nonhomogeneous armor fabricated from various plies of unidirectional fiber glass fabric, laid up with alternate plies oriented 90 degrees to each other and bonded together, usually with a general-purpose polyester thermosetting resin. Designed during World War II primarily as a fragment-resisting material, it is significantly inferior to standard metallic armors in protection against small-arms fire, especially of the armor-piercing variety. This armor is of primary interest here because of its applications as fragment protection armor and as part of various composite armors.

2.2.2.10 Woven-Roving Fiber Glass Organic Armor: This material, similar in many physical respects to Doron, also has similar capabilities and applications in the field of ballistic protection. It costs less than Doron, however, and has slightly improved ballistic properties. For these reasons, woven-roving fiber glass is replacing Doron, in some cases, as a backing material in composite armors.

2.2.2.11 Composite Armor Systems: Composite armor systems represent a wide range of combinations and capabilities, including some that offer exceptional possibilities for future development.

Composite armors may be divided into five general types; each of these general types and pertinent examples from each type will be discussed separately. The five general types of composite armor systems are:

- Metal-metal composites
- Metal-ceramic composites
- Metal-organic composites
- Metal-ceramic-organic composites
- Ceramic-organic composites

2.2.2.11.1 Metal-Metal Composites: A considerable amount of work has been done on ballistic evaluation of various metal-metal composite armors. Basically, such composites fall into two general categories: (1) wherein the separate layers of armor material are laminated or otherwise bonded together to form an integral unit, and (2) wherein the separate material layers are in physical contact, but remain unjoined except for any mounting hardware that may hold them together when installed. The separate layers of metal may be either of the same material or of different materials, and may vary widely in layer thicknesses.

2.2.2.11.2 Metal-Ceramic Composites: See classified data in Volume II (USAAMRDL Technical Report 71-41B).

2.2.2.11.3 Metal-Organic Composites: See classified data in Volume II (USAAMRDL Technical Report 71-41B).

2.2.2.11.4 Metal-Ceramic-Organic Composites: See classified data in Volume II (USAAMRDL Technical Report 71-41B).

2.2.2.11.5 Ceramic-Organic Composites: Armor composites of this type include several that are among the most promising in terms of future development as ballistic protection devices. With one exception, the general type of ceramic-faced composite armor conform to Specification MIL-A-46103 (MR). The general types and pertinent specific examples are discussed in the following paragraphs. Included in this general category are the following composites:

- Boron carbide (B_4C)-Doron-type laminates
- Alumina-Doron-Type laminates
- Doron and other Doron-type laminates
- Silicon carbide-Doron-type laminates
- Beryllium oxide-Doron-type laminates
- Titanium carbide-woven roving fiber-glass-type laminates

- Titanium diboride-woven roving fiber-glass-type laminates

- Miscellaneous ceramic-organic composites

NOTE: In most of the composites involving Doron, there is a parallel and basically equivalent composite in which woven-roving fiber glass replaces Doron as one element.

2.2.2.11.5.1 Boron Carbide (B_4C)-Doron-Type Laminates: The experimental B_4C-Doron-type laminates must be regarded at this time as one of the best possible armor prospects for limited multihit protection. Probable merit ratings are significantly in excess of other armors discussed to this point. Thus, areal densitites are very low, and the weight advantages for aircraft armor applications are significant. This type of armor is available only in experimental quantities at the present time. In addition, the cost is high. Efforts are in process to increase production capabilities and to reduce cost. As is true of most armors in this general category, structural capabilities are largely lacking and, thus, use of the armor is restricted in that sense.

2.2.2.11.5.2 Alumina-Doron-Type Laminates: Composite armors of this general type are inferior in ballistic properties to the more advanced composite armors included in this general category. As was true of the B_4C-Doron armor, this type of armor has a limited multihit capability, and structural properties are minimal. Cost, however, is significantly lower, and the material is more readily available.

2.2.2.11.5.3 Doron and Doron-Type Laminates: Doron (discussed previously) and Doron-type laminates are in themselves inferior armor materials, especially against armor-piercing projectiles. Their chief use is as elements of composite or spaced armors, where they serve as backup material.

2.2.2.11.5.4 Silicon Carbide-Doron-Type Laminates: Based on limited testing, these armors fall between the more advanced B_4C-Doron and Al_2O_3-Doron composites, in terms of ballistic capabilities. With further development, armors of this type should also prove to be significantly less expensive than the B_4C-Doron composites. Multihit and structural capabilities will be limited, as was true of the other ceramic-organic composites.

2.2.2.11.5.5 Titanium Carbide-Woven Roving Fiber-Glass-Type Laminates: This armor, together with titanium diboride-woven roving fiber glass composites (refer to paragraph 2.2.2.11.5.6), represents some of the most recent development work in the armor field. Very limited ballistic test data suggest much promise for this armor if its availability can be improved and the present high price reduced.

2.2.2.11.5.6 Titanium Diboride-Woven Roving Fiber-Glass-Type Laminates: To an even greater extent that titanium carbide-woven roving fiber glass composites, this material exhibits extremely effective ballistic protection capabilities in those limited areas for which data are currently available. Here again, utility of this armor is greatly hampered by limited availability and high cost.

2.2.2.11.5.7 Miscellaneous Ceramic-Organic Composites: A number of other ceramic-organic composite armor arrays have been explored. These miscellaneous ceramic-organic composites are largely developmental and probably not applicable for serious consideration at the present time.

2.2.2.12 Transparent-Type Nonhomogeneous Solid Armors: In addition to the Plexiglas and Lexan transparent armors discussed under the homogeneous solid armors protection of this section, there are a number of nonhomogeneous types of transparent solid armor to be considered. All of these are experimental in terms of their ballistic properties status. Of these experimental types, some are available commercially, while others are purely developmental at this time. Significant examples of each of these types of transparent armor are discussed in the following paragraphs.

2.2.2.12.1 Commercially Available Materials: Included in this classification are various laminated bullet-resistant glasses such as Safetee glass, reactor window glass, etc.

See classified data in volume II (USAAMRDL Technical Report 71-41B).

2.2.2.13 Developmental Transparent Armors: Considerable work has been done and is still under way on the development of superior transparent armors. The work involves investigation of various assemblies and thicknesses of glass and plastic materials, bonded and unbonded. The developmental effort is centered in three basic areas. Included are:

- Laminated bonded organic
- Laminated bonded inorganic
- Laminated bonded inorganic-organic

See classified data in Volume II (USAAMRDL Technical Report 71-41B).

2.2.3 SPACED ARMOR SYSTEMS

Spaced armor covers all designs having spaces between armor elements. All spaced armor would fall into the armor system (rather than material) category and would, of course, be nonhomogeneous in nature. Although considerable effort has been expanded in this area over recent years, and although a number of types of spaced armor have been evaluated ballistically, no military-type specifications yet define the properties of such armor. Thus, as mentioned earlier, all such armors must be classed as experimental.

With few exceptions, much of the work in this field to date has involved the use of some of the older types of armor material, rather than the more advanced armors. Perhaps for this reason, among others, velocity merit ratings for the resulting spaced armor systems often tend to fall under the established minimum values for experimental armors worthy of serious consideration for design purposes. In addition, some of the merit ratings that have been obtained tend to vary considerably, even for the same armor when tests are repeated.

Because of the overall thicknesses involved in two or more layers of armor material separated by an amount of air space, space limitations would often tend to limit application of such systems in the case of aircraft armor design. In general, requirements for mounting this type of armor would often tend to be a little more complicated than for solid armors. Procurement would also offer some problems in most cases.

In view of these considerations, with a few exceptions, spaced armor systems thus cannot presently be given serious consideration for aircraft purposes. It is conceivable, of course, that future developments may change this outlook appreciably.

2.2.3.1 Spaced Armor Protection Mechanisms: See classified data in Volume II (USAAMRDL Technical Report 71-41B).

2.3 ARMOR DATA

There is a great deal of data available on the capability of armor materials to defeat small-arms projectiles. The data are usually presented

to show V_{50} protection limits for a range of specific projectiles impact velocities and angles of obliquities for corresponding areal densities of a specific armor type and material.

Figures 195 through 201 show representative curves for high-hardness steel, titanium, aluminum alloys, and unbonded nylon armor materials against various size projectiles and fragment simulators.[10]

Table XXX is a listing of some of the nonballistic properties of armor materials that must be considered in their design applications. This includes physical/mechanical properties, fabrication and structural capabilities, environmental resistances, availability, multihit capability, and approximate cost per pound.

Table XXXI is the index from Reference 10 on armor ballistic performance and range-velocity curves for armor materials and projectiles. It is presented to indicate the type of data available.

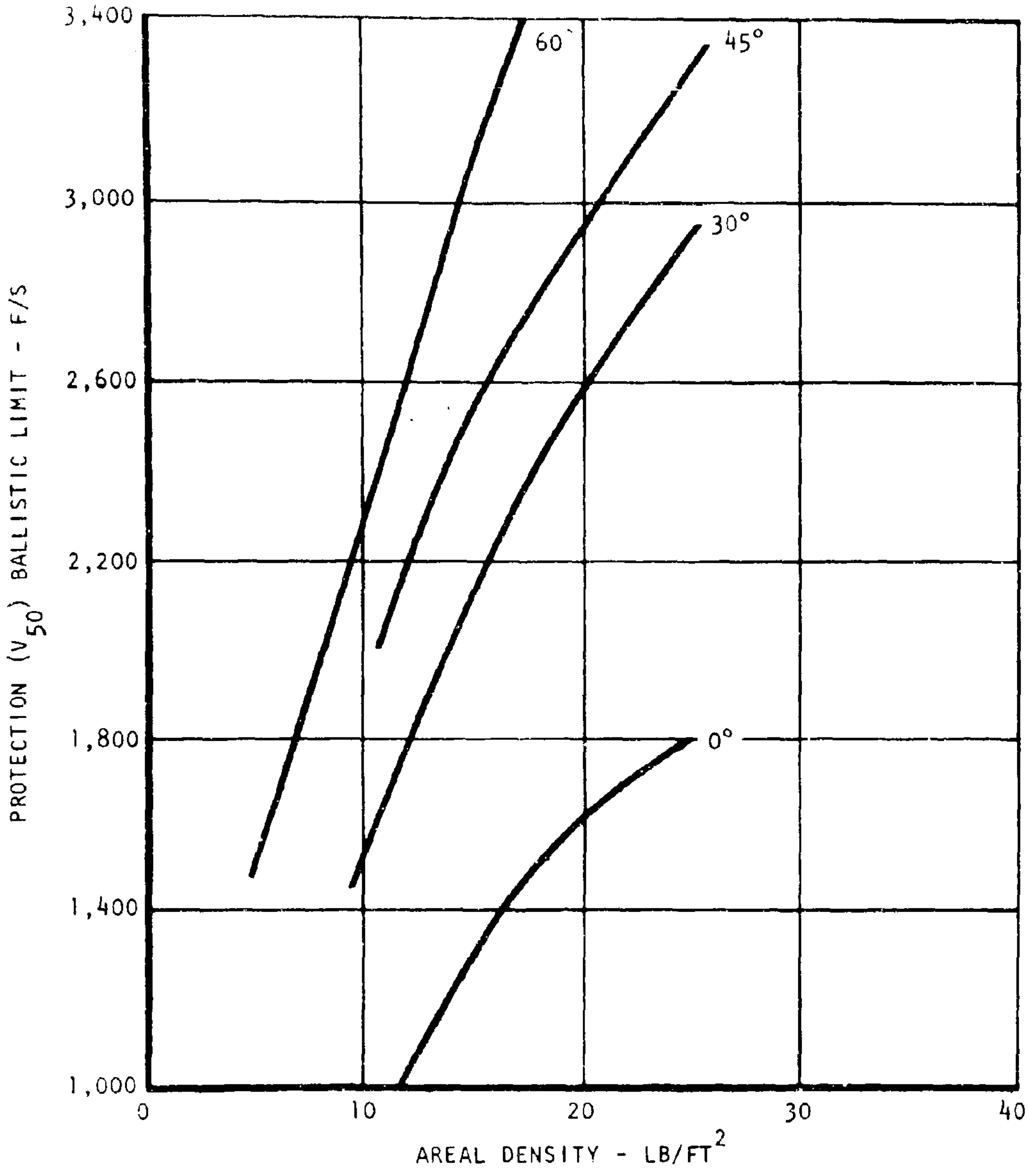


Figure 195. Protection Provided by Wrought High-Hardness Steel Armor, Specification MIL-S-46100 (MR), Against Caliber .50 AP M2 Projectiles at Various Obliquities.

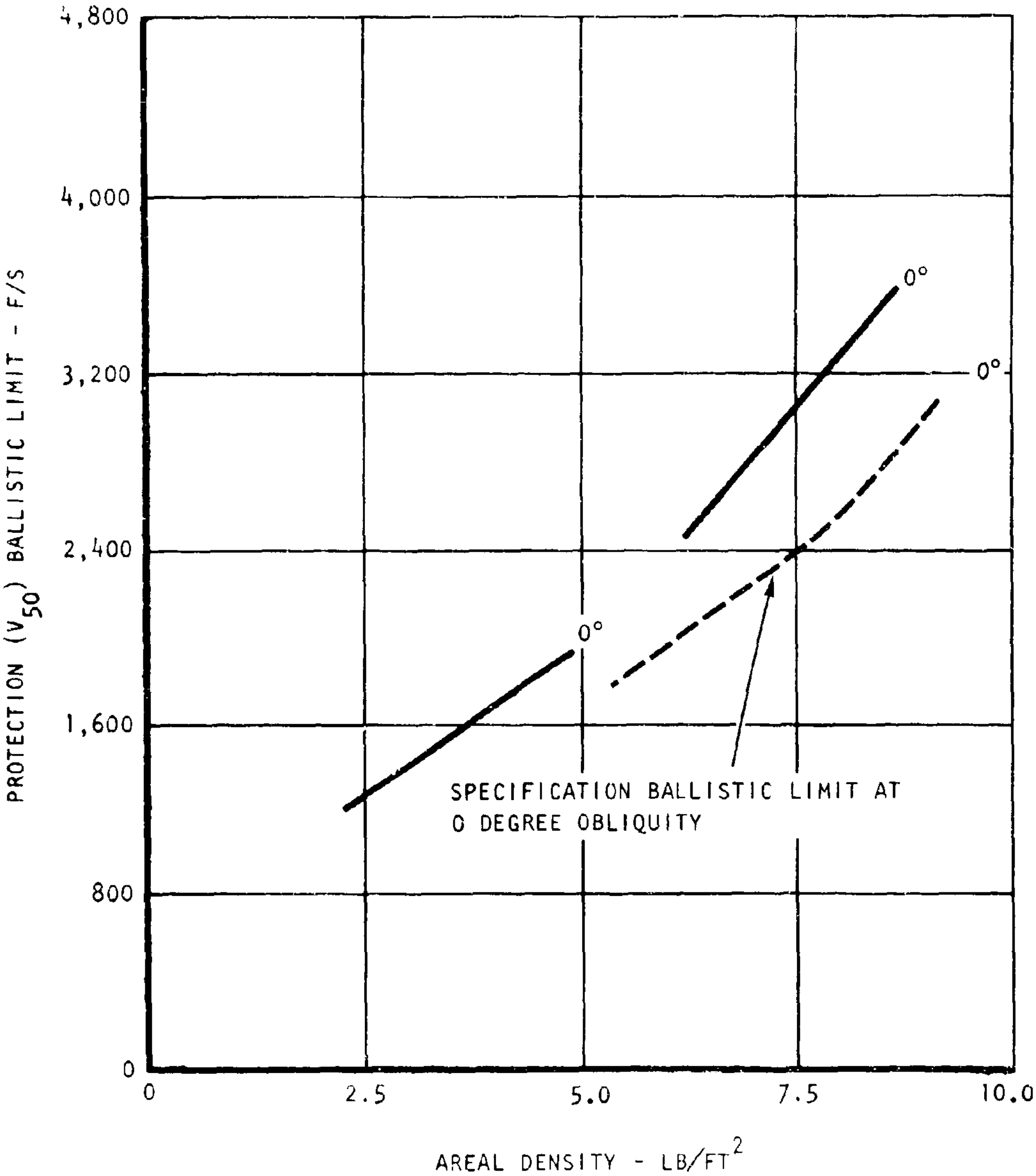


Figure 196. Protection Provided by Titanium Alloy Armor, Specification MIL-T-46077 (MR), Against Caliber .30 (44 Grain) Fragment-Simulating Projectiles at 0 Degree Obliquity.

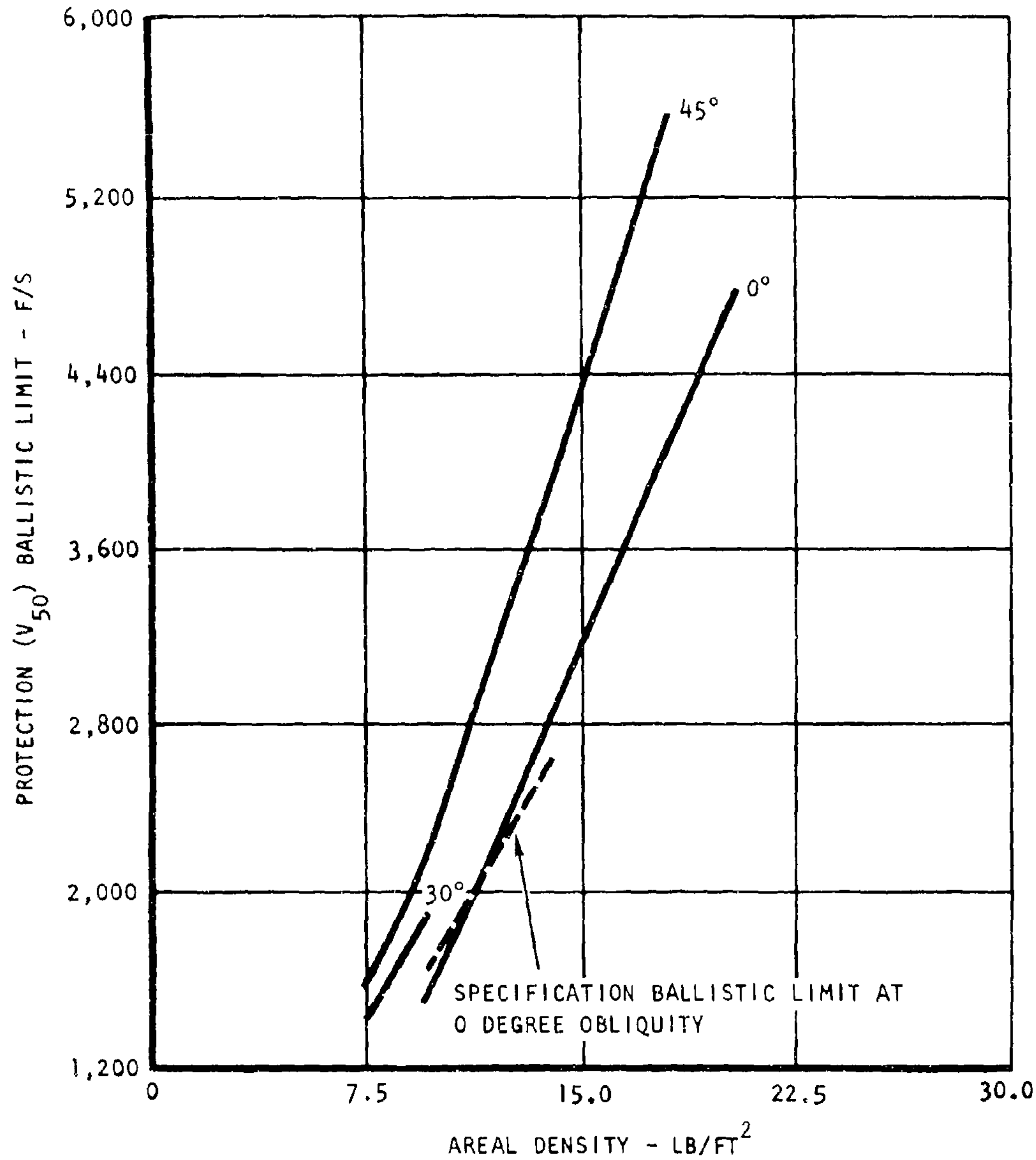


Figure 197. Protection Provided by Aluminum Alloy Armor, Specification MIL-A-46027 (MR) Against Caliber .50 (207 Grain) Fragment-Simulating Projectiles at Various Obliquities.

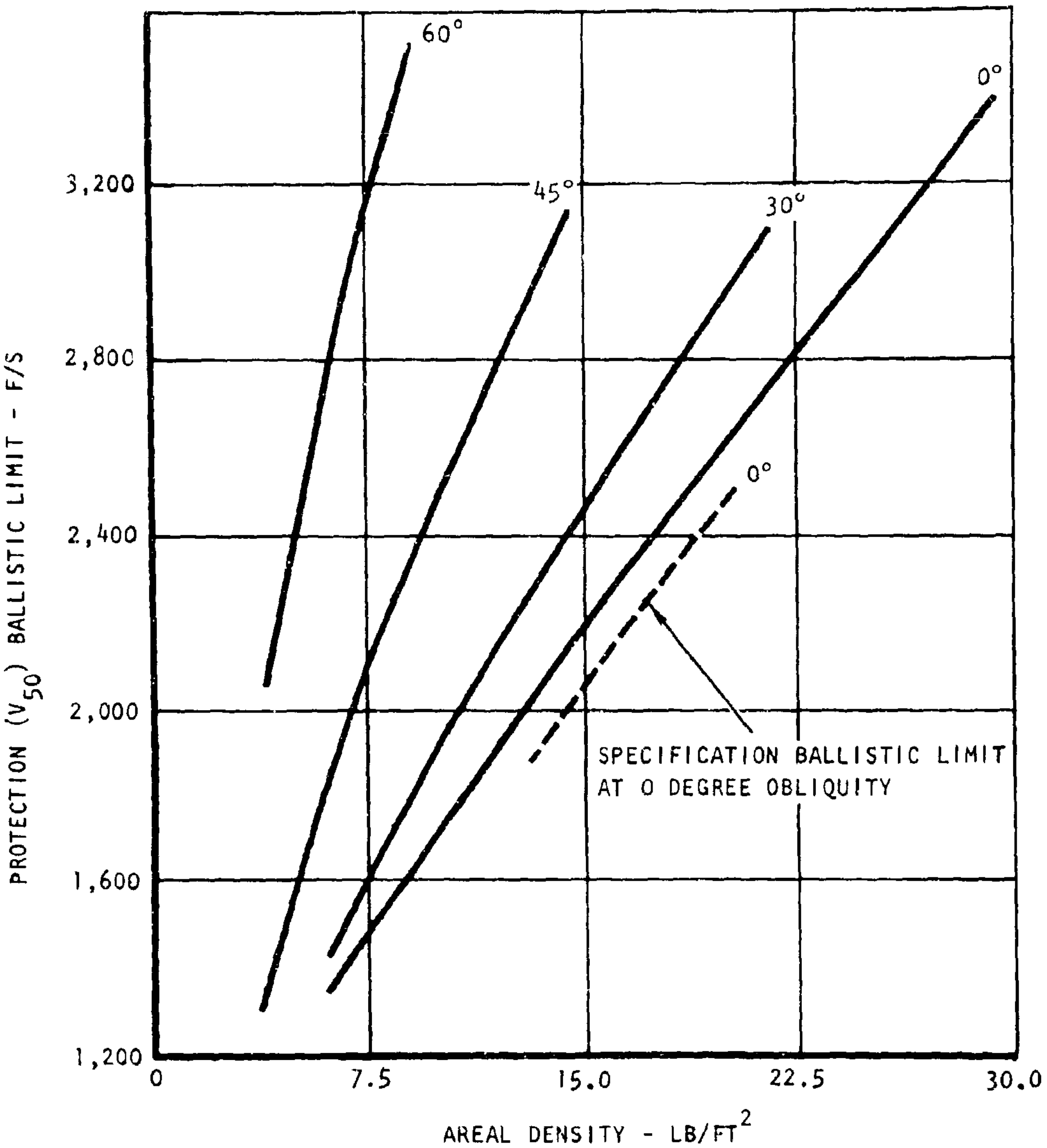


Figure 198. Protection Provided by Aluminum Alloy Armor, Specification MIL-A-46063 (MR), Against Caliber .30 AP M2 Projectiles at Various Obliquities.

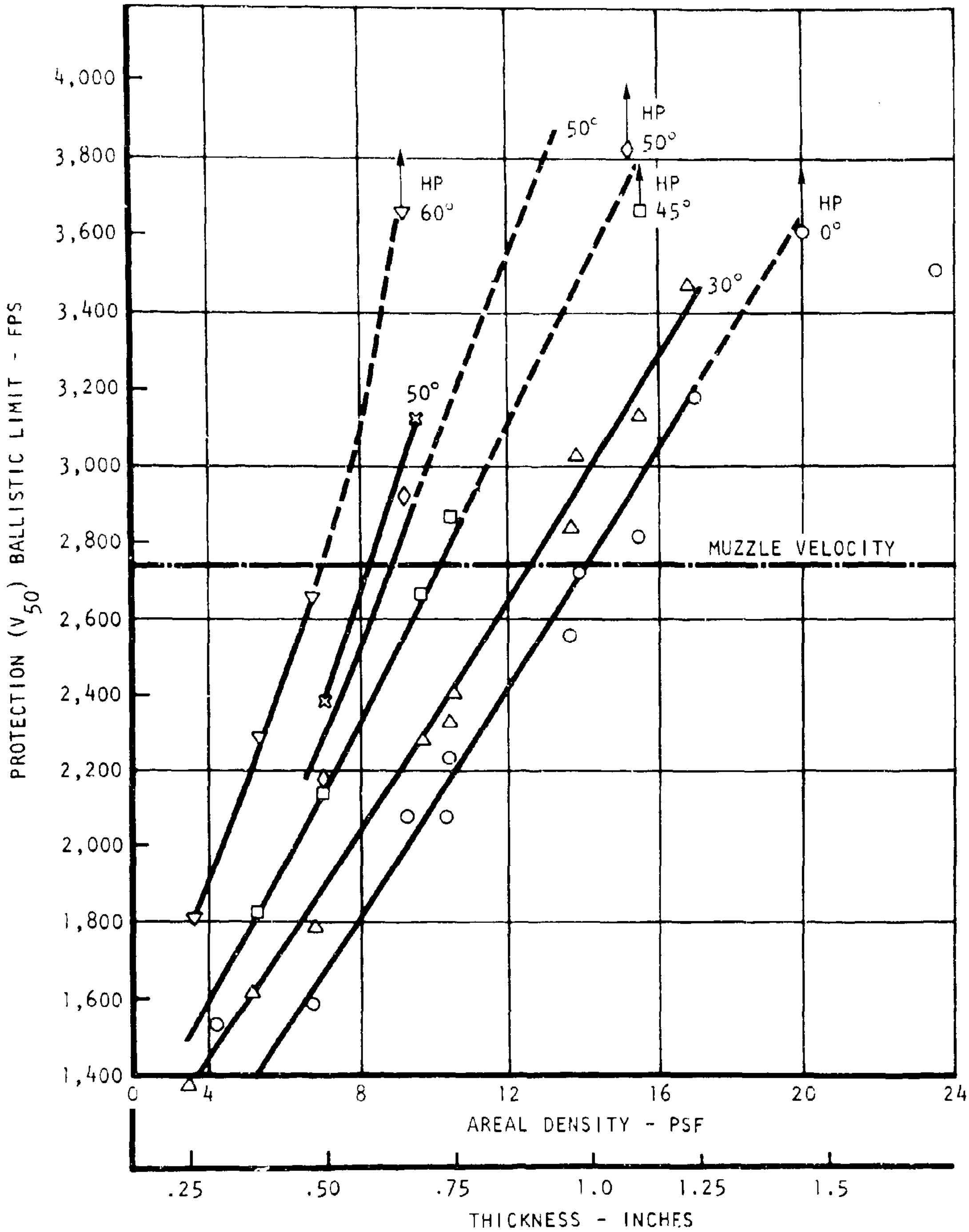


Figure 199. Protection Provided by Aluminum Alloy Armor (5083) Against 7.62-MM M80 Ball Projectiles at Various Obliquities.

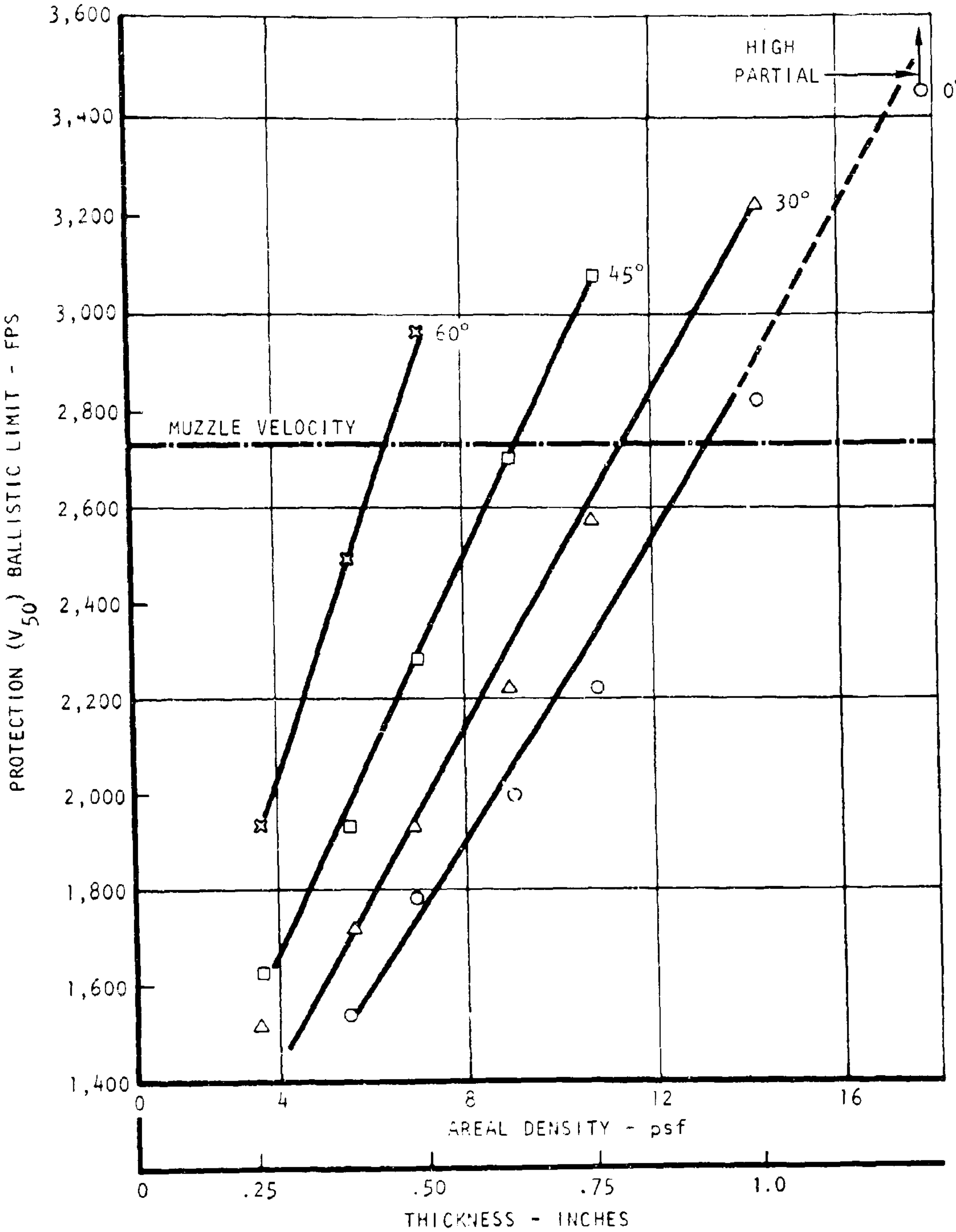


Figure 200. Protection Provided by 7039 Aluminum Armor Against 7.62-MM M80 Ball Projectiles at Various Obliquities.

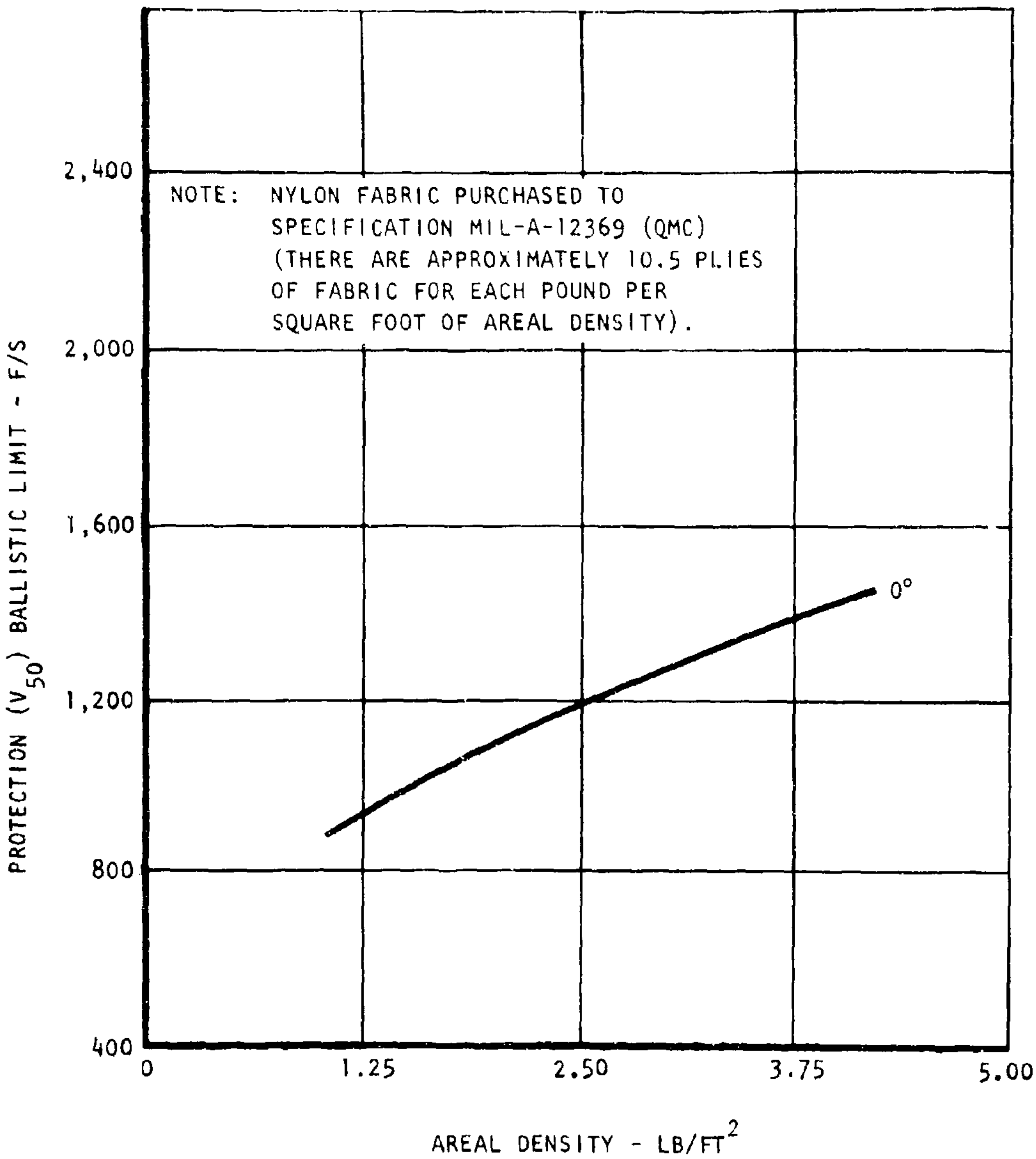


Figure 201. Protection Provided by Unbonded Nylon Against Caliber .50 (207 Grain) Fragment-Simulating Projectiles at 0 Degrees Obliquity.

TABLE XXX. NONBALLISTIC PROPERTIES OF ARMOR MATERIALS

Material	Specification	Physical/Mechanical Properties*: Weight (psi/in./thick)	Hardness	Elastic Modulus (psi x 10^6)	Tensile Strength (psi)	Magnetic	Fabrication Capabilities: Shaping/Forming	Martinizing	Welding	Structural C…: Primary Load	Secondary Load
Aluminum alloy, 2021-T4	MIL-A-7169A	14.40	128 BHN	10.6	60,000 min	No	Yes	Yes	No	Yes	Yes
Aluminum alloy, 5083	MIL-A-46027 (MR)	13.83	100 BHN	10.3	44,000 min	No	Yes	Yes	Yes	Yes	Yes
Aluminum alloy, 7039-T6	MIL-A-45063 (MR)	14.22	128 BHN	10.2	57,000 min	No	Yes	Yes	Yes	Yes	Yes
Aluminum alloy, 7075	N/A	14.54	150 BHN	10.3	70,000 min	No	Yes	Yes	No	Yes	Yes
Ceramic composites											
85% alumina Al_2O_3-doron	N/A	F 17.78 B 10.32	F Knoop 1950	F 28-35 B 3	N/A	No	Yes	No	No	No	Yes
85% Al_2O_3 WR fiber glass	N/A	F 17.78 B 10.6	F Knoop 1950	F 28-35 B 3	N/A	No	Yes	No	No	No	Yes
94% Al_2O_3-aluminum (2C24)	N/A	F 18.62 B 14.44	F Knoop 2050	F 41-50 B 3	N/A	No	Yes	No	No	Yes	Yes
94% Al_2O_3-aluminum (5083)	N/A	F 18.82 B 13.83	F Knoop 2050	F 41-50 B 10.3	N/A	No	Yes	No	No	Yes	Yes
94% Al_2O_3-aluminum (3083)	N/A	F 18.82 B 14.22	F Knoop 2050	F 41-50 B 10.2	N/A	No	Yes	No	No	No	Yes
94% Al_2O_3-doron	N/A	F 18.62 B 10.32	F Knoop 2050	F 41-50 B 3	N/A	No	Yes	No	No	Yes	Yes
94% Al_2O_3-titanium (6Al-4V)	N/A	F 18.82 B 23.2	F Knoop 2050	F 41-50 B 16.2	N/A	No	Yes	No	No	No	Yes
94% Al_2O_3-WR fiber glass	N/A	F 18.82 B 10.6	F Knoop 2050	F 41-50 B 3	N/A	No	Yes	No	No	No	Yes
Beryllium oxide (BeO)-doron	N/A	F 15.5 B 10.32	F Knoop 1300	F 40-60 B 3	N/A	No	Yes	No	No	No	Yes
BeO-WR fiber glass	N/A	F 15.5 B 10.6	F Knoop 1500	F 40-60 B 3	N/A	No	Yes	No	No	Yes	Yes
Boron carbide (B_4C)-aluminum (3083	N/A	F 12.97 B 13.83	F Knoop 2800	F 65 B 10.3	N/A	No	Yes	No	No	No	Yes
B_4C-boron	N/A	F 12.97 B 10.32	F Knoop 2800	F 65 B 3	N/A	No	Yes	No	No	No	Yes
B_4C-WR fiber glass	N/A	F 12.97 B 10.6	F Knoop 2800	F 65 B 3	N/A	No	Yes	No	No	No	Yes
Silicon carbide (SiC)-doron	N/A	F 16.15 B 10.32	F Knoop 2700	F 50 B 3	N/A	No	Yes	No	No	No	Yes
SiC-silicon bonded B_4C-doron	N/A	F 13.70 B 10.32	F Knoop 2600	F 50 B 3	N/A	No	Yes	No	No	No	Yes
SiC-WR fiber glass	N/A	F 16.15 B 10.6	F Knoop 2600	F 50 B 3	N/A	No	Yes	No	No	No	Yes
Titanium carbide (TiC) WR fiber glass	N/A	F 29.7 B 10.3	F R_A 93.5	F 45-60 B 3	N/A	No	Yes	No	No	No	Yes
Titanium diboride (TiB_2)-WR fiber glass	N/A	F 22.4 B 10.6	F Knoop 3000	F 54-77 B 3	N/A	No	Yes	No	No	No	Yes
Doron	N/A	10.32	Rockwell M-110	3	63,000	No	Yes	Yes	No	No	Yes
Fiber glass, WR	N/A	10.6	Rockwell M-110	3	54,000	No	Yes	Yes	No	No	Yes
Nylon, bonded (18% resin)	N/A	-	-	-	-	No	Yes	Yes	No	No	No
Nylon, untended	MIL-C-12369	-	-	-	-	No	Yes	No	No	No	No
Plexiglas	N/A	6.3	Rockwell M-93	.45	10,500	No	Yes	Yes	No	No	No
Polycarbonate (Lexan)	N/A	6.3	Rockwell M-70	.35	9,500	No	Yes	Yes	No	No	No
Steel, dual-hardness	MIL-S-46099 (MR)	40.8	Front 59-62 R_C Rear 50-53 R_C	30	Front 300,000 Rear 230,000	Yes	Yes	Yes	Yes	Yes	Yes
Steel, face-hardened	JAN-A-784	40.8	Front 700 BHN Rear 400 BHN	30	-	Yes	Yes	Yes	Yes	Yes	Yes
Steel, Hadfield-manganese	MIL-S-13259	40.8	170-200 BHN	24-30	131K-158K	Yes	Yes	Yes	Yes	Yes	Yes
Steel, hard (T 49) sheet	N/A	40.8	R_C49	30	240,000	Yes	Yes	Yes	Yes	Yes	Yes
Steel, rolled (300 BHN)	N/A	40.8	269-401 BHN	30	150,000	Yes	Yes	Yes	Yes	Yes	Yes
Steel, wrought high-hardness	MIL-S-46100 (MR)	40.8	485-530 BHN	30	250K-276K	Yes	Yes	Yes	Yes	Yes	Yes
Steel, wrought homogeneous (std)	MIL-S-12560 (Ord)	40.8	269-401 BHN	30	134K-202K	Yes	Yes	Yes	Yes	Yes	Yes
Titanium alloy, 6Al-4V (ELI grade)	MIL-T-16077 (MR)	23.2	R_C 30-40	17	120,000 min	No	Yes	Yes	Yes	Yes	Yes
Transparent composites		F 11.3-14.1 B 6.3	F B R_M 70-93	F 6.8-12.7 B .35-.45	N/A	No	Yes	Yes	No	No	No

F - facing, B - backing
WR - Woven roving
Heat treated dual-hardness steel can be machined; ausformed - grinding only.

X. NONBALLISTIC PROPERTIES OF ARMOR MATERIALS

tion Capabilities		Structural Capabilities				Environmental Resistance						
Martinizing	Welding	Primary Load	Secondary Load	Attachment Methods	Joining Methods	Shock - Vibration	Temp Extremes (-65 - +200°F)	Corrosion	Flamm-ability	Availability of Materials	Multi-Hit Capability	Approx Cost (per lb)
Yes	No	Yes	Yes	Mech	Mech	Excellent	Good	Fair	Excellent	Unlimited	Full	$0.60
Yes	Yes	Yes	Yes	Mech & weld	Weld	Excellent	Good	Good	Excellent	Unlimited	Full	0.75
Yes	Yes	Yes	Yes	Mech & weld	Weld	Excellent	Good	Good	Excellent	Unlimited	Full	0.75
Yes	No	Yes	Yes	Mech	Mech	Excellent	Good	Fair	Excellent	Unlimited	Full	0.60
No	[illegible]	No	Yes	Mech	Mech	Good	Good	Good	Good	Limited	Limited	4.50
No	No	No	Yes	Mech	Mech	Good	Good	Good	Good	Limited	Limited	3.50
No	No	Yes	Yes	Mech	Mech	Good	Good	Fair	Excellent	Limited	Limited	4.00
No	No	Yes	Yes	Mech	Mech	Good	Good	Good	Excellent	Limited	Limited	4.00
No	No	Yes	Yes	Mech	Mech	Good	Good	Good	Excellent	Limited	Limited	4.00
No	No	No	Yes	Mech	Mech	Good	Good	Good	Good	Limited	Limited	5.00
No	No	Yes	Yes	Mech	Mech	Good	Good	Good	Excellent	Limited	Limited	7.00
No	No	No	Yes	Mech	Mech	Good	Good	Good	Good	Limited	Limited	4.00
No	No	No	Yes	Mech	Mech	Good	Good	Good	Good	Limited	Limited	25.00
No	No	No	Yes	Mech	Mech	Good	Good	Good	Good	Limited	Limited	25.00
No	No	Yes	Yes	Mech	Mech	Good	Good	Good	Excellent	Limited	Limited	21.00
No	No	No	Yes	Mech	Mech	Good	Good	Good	Good	Limited	Limited	23.00
No	No	No	Yes	Mech	Mech	Good	Good	Good	Good	Limited	Limited	22.00
No	No	No	Yes	Mech	Mech	Good	Good	Good	Good	Limited	Limited	8.00
No	No	No	Yes	Mech	Mech	Good	Good	Good	Good	Limited	Limited	10.00
No	No	No	Yes	Mech	Mech	Good	Good	Good	Good	Limited	Limited	7.00
No	No	No	Yes	Mech	Mech	Good	Good	Good	Good	Limited	Limited	25.00
No	No	No	Yes	Mech	Mech	Good	Good	Good	Good	Limited	Limited	25.00
Yes	No	No	Yes	Mech	Mech	Excellent	Good	Good	Good	Unlimited	Limited	3.00
Yes	No	No	Yes	Mech	Mech	Excellent	Good	Good	Good	Unlimited	Limited	2.00
Yes	No	No	No	Mech	Mech	Excellent	Good	Good	Good	Unlimited	Limited	2.50
No	No	No	No	Mech	Mech	Excellent	Good	Good	Good	Unlimited	Limited	1.25
Yes	No	No	No	Mech	Mech	Good	Poor	Fair	Poor	Unlimited	Limited	1.50
Yes	No	No	No	Mech	Mech	Good	Fair	Fair	Good	Unlimited	Limited	4.00
Yes	Yes	Yes	Yes	Mech & weld	Weld	Good	Excellent	Protection reqd	Excellent	Limited	Full	3.25
Yes	Yes	Yes	Yes	Mech & weld	Weld	Good	Excellent	Protection reqd	Excellent	Limited	Full	0.80
Yes	Yes	Yes	Yes	Mech & weld	Weld	Good	Excellent	Protection reqd	Excellent	Limited	Full	0.25
Yes	Yes	Yes	Yes	Mech & weld.	Weld	Excellent	Excellent	Protection reqd	Excellent	Unlimited	Full	
Yes	Yes	Yes	Yes	Mech & weld	Weld	Excellent	Excellent	Protection reqd	Excellent	Unlimited	Full	0.60
Yes	Yes	Yes	Yes	Mech & weld	Weld	Excellent	Excellent	Protection reqd	Excellent	Unlimited	Full	0.25
Yes	Yes	Yes	Yes	Mech & weld	Weld	Excellent	Excellent	Protection reqd	Excellent	Unlimited	Full	0.60
Yes	Yes	Yes	Yes	Mech & weld	Weld	Excellent	Excellent	Excellent	Excellent	Limited	Full	4.50
Yes	No	No	No	Mech	Mech	Good	Fair	Fair	Fair	Limited	Limited	10.00

TABLE XXXI. INDEX TO ARMOR BALLISTIC PERFORM
AND PROJECTILE RANGE-VELOCITY CURVES

Material	Specification	Fragment-Simulating Projectiles - (FPS's)								Ball-Type Projectiles			
		Cal .100 1.35 Grain	Cal .125 2.65 Grain	Cal .15 5.85 Grain	Cal .22 17 Grain	Cal .30 44 Grain	Cal .45 147 Grain	Cal .50 207 Grain	20 mm 830 Grain	5.58 mm Ball Grain	7.62 mm Ball M80	Cal .30 Ball M2	Cal Ba N
Range Velocity Curves		←				A-1			→	A-2	A-3	A-4	A
Ballistic performance curves													
Aluminum alloy, 2024-T4								A-38	A-54	A-62	A-68	A-74	
Aluminum alloy, 5083	MIL-A-46027 (MR)							A-39	A-55	A-63	A-69	A-75	A
Aluminum alloy, 7039-T8	MIL-A-46063 (MR)												
Aluminum alloy, 7075	N/A				A-20	A-28							
Ceramic composites													
85% alumina (Al_2O_3) - doron	N/A												
85% Al_2O_3 - WR fiber glass	N/A				A-21								
94% Al_2O_3 - aluminum (2024)	N/A												
94% Al_2O_3 - aluminum (5083)	N/A												
94% Al_2O_3 - aluminum (7039)	N/A												
94% Al_2O_3 - doron	N/A					A-29	•	A-40			A-70	A-76	
94% Al_2O_3 - titanium (6Al-4V)	N/A												
94% Al_2O_3 - WR fiber glass	N/A												
Beryllium oxide (BeO) - doron	N/A											A-77	
BeO - WR fiber glass	N/A												
Boron carbide (B_4C) - aluminum (5083)	N/A							A-41				A-78	
B_4C - doron	N/A							A-42				A-79	A
B_4C - WR fiber glass	N/A												
Ceramic-faced, lightweight	MIL-A-46103 (MR)												
Silicon carbide (SiC) - doron	N/A											A-80	
SiC - silicon bonded B_4C - doron	N/A												
SiC - WR fiber glass	N/A												
Titanium carbide (TiC) - WR fiber glass	N/A												
Titanium diboride (TiB_2) - WR fiber glass	N/A												
Doron	N/A		•	A-16	A-22	A-20	•	A-43	A-56				
Fiber glass, woven roving (WR)	N/A									A-64		A-81	
Magnesium (13Li-6Al)	N/A			•	•	•		•	•				
Nylon, bonded (18% resin)	N/A	•	•	A-17	A-23	A-31	•	A-44	A-57				
Nylon, unbonded	MIL-C-12369	•	•	A-18	A-24	A-32	•	A-45					
Plexiglas	N/A										A-71	A-82	
Polycarbonate (lexan)	N/A				A-25							A-83	
Steel, dual-hardness	MIL-S-46099 (MR)							A-46				A-84	
Steel, face-hardened	JAM-A-784											A-85	
Steel, Hadfield manganese	MIL-S-13259				A-26	A-33	•	A-47					
Steel, Hard (R_c42) sheet.	N/A			A-19	A-27	A-34	•	A-48					
Steel, rolled (300 BHN)	N/A					A-35		A-49	A-58				
Steel, rolled homogeneous	MIL-A-258												
Steel, rolled nonmagnetic	MIL-A-434												
Steel, wrought high-hardness	MIL-S-46100 (MP)							A-50	A-59			A-88	
Steel, wrought homogeneous (std)	MIL-S-12560 (Ord)					A-36		A-51	A-60	A-65		A-87	
Titanium alloy, 4Al-4V	N/A												
Titanium alloy, 6Al-4V	N/A							•	•				
Titanium alloy, 6Al-4V (ELI grade)	MIL-T-46077 (MR)					A-37		A-52	A-61	A-68		A-88	
Transparent composites (see also tables A-II through A-VII)								A-53		A-67			

* Data presented in Report No. ABI-100 (Special Rev 1)

NOTE THE LETTER A BEFORE THE PRESENTED FIGURE NUMBER DENOTES THAT IT IS CONTAINED IN AMMRC REPORT NO. ABI-100 (SPECIAL), REV 1

TABLE XXVI. INDEX TO ARMOR BALLISTIC PERFORMANCE AND PROJECTILE RANGE-VELOCITY CURVES

		Ball-Type Projectiles				Armor-Piercing Projectiles											
Cal .50 207 Grain	20 mm 830 Grain	5.58 mm Ball Grain	7.62 mm Ball M80	Cal .30 Ball M2	Cal .50 Ball M2	7.62 mm AP M61	Cal .30 AP M2	Cal .50 AP M2	12.7 mm API B-32 (Soviet)	14.5 mm API B-32 (Soviet)	14.5 mm API BS-41 (Soviet)	20 mm AP M75	20 mm AP M95	20 mm AP-T M95	20 mm HVAP-T DM-43 (Hispano-Suiza)	20 mm AP HEI-RIA (Hispano-Suiza)	23 mm API-T BZT (Soviet)
		A-2	A-3	A-4	A-5	A-6	A-7	A-5	A-8	A-9	A-10	A-11	A-12	A-12	A-13	A-14	A-15
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A-53		A-67															

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13. ABSTRACT
An extensive literature and information search was conducted to identify military aircraft small-arms protection enhancement techniques developed during the past 10 years. This data was analyzed and used to develop a comprehensive survivability design for incorporation of ballistic protection features in U.S. Army aircraft. The design guide is structured for use by aircraft configuration and subsystem design organizations. It provides guidance for overall survivability design considerations and detailed information on specific enhancement techniques. The greatest amount of the design guide information is unclassified and is contained in this document to facilitate its use by individual designers. Special classified information has been placed in Volume II (USAAMRDL Technical Report 71-41B) for use by design specialty areas.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aircraft Vulnerability						
Aircraft Survivability						
Survivability Enhancement Techniques						
Small-Arms Ballistic Protection						
Ballistic Damage Tolerance						

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